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No. 1

OBSERVATIONS
ON THE
STRUCTURE
AND
DRAUGHT
OF
WHEEL-CARRIAGES.

By J. JACOB.

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TO THE

READER.

THE improvement of wheel-carriages having lately much engaged the public attention, it became the duty of one who makes their conſtruction a principal part of his profeſſion, to take it more particularly under conſideration.

With this view I attended the experiments made laſt year, by order of the Society for the encouragement of arts, manufactures, and commerce, in the

Strand. The ſummer vacation interrupting thoſe experiments before any ſatisfactory concluſions could be drawn from them, I was reduced to the neceſſity of proſecuting my enquiries, by making ſome experiments myſelf.

A number of very perplexing ones, and the reſult of others as perfectly ſimple, gave riſe to the following Obſervations: the publication of which is rather intended to make them generally known, in order that they may be confirmed or refuted by the experience of others, than to gratify any vanity I may be ſuppoſed to entertain in appearing as an author.

That I have been enabled indeed to acquit myſelf with any degree of propriety as a writer, is owing to the friendly aſſiſtance and diſtinguiſhed abilities of Dr. KENRICK; to whom I think it incumbent on me, therefore, to make my acknowledgments on this occaſion.

JOSEPH JACOB.

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OBSER-

OBSERVATIONS
ON THE
STRUCTURE AND DRAUGHT
OF
WHEEL-CARRIAGES.

PART FIRST.

ON THE DRAUGHT OF CARRIAGES IN GENERAL.

PREPARATORY to the conſideration of the ſtructure and draught of wheel-carriages in particular, it is neceſſary to enter into ſome illuſtration of the principles of the draught of carriages in general; the moſt obvious method of acquiring the true knowledge of the operation of compound and complicated machines, being, to proceed gradually from that of the moſt uniform and ſimple, to the more multiform and complex.

SECTION I.

Of the nature and economy of draught.

DRAUGHT in general may be defined, as the generation and continuation of local * motion in a body at reſt by another body, at firſt equally deſtitute of motion; the motion given to a body in traction not being communicated, as in percuſſion by another body already in motion.

HUYGENS, Dr. Wallis, and many others, have treated diffuſely of the communication of motion from body to body by percuſſion; and have ſufficiently ſhewn, that the velocity to be thus communicated to a body at reſt will always be in proportion to the difference between the momentum of the moving body and the vis inertiæ, or dead weight, of the body moved. For no body can communicate to another a greater quantity of motion than it has in itſelf; and, as the quantity of motion in every body is com-

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* I ſay local motion, in order to diſtinguiſh between the motion of the parts of a body and that of the whole. Thus a wheel may revolve round its axis without having any local motion, as it really does when the axis is at reſt: the local motion of the whole wheel depending on the rectilinear motion of its centre.

Fig. 1.

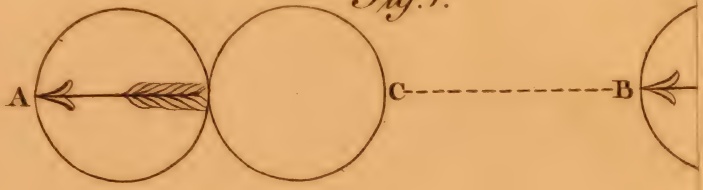
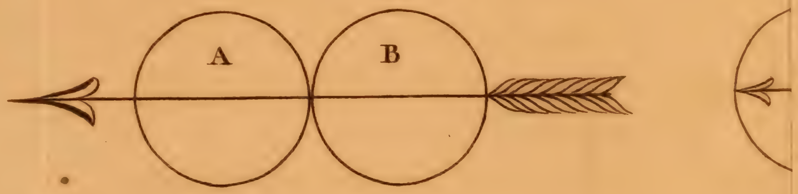
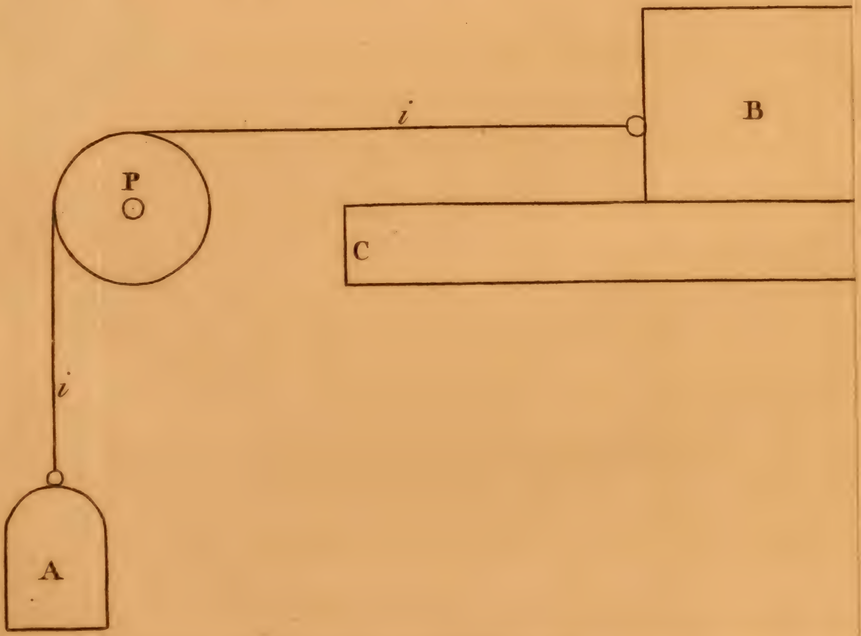


Fig. 2.





compounded or made up of its weight and velocity, it is plain, that, be the velocity of a very little body ever ſo great, it will communicate to a body much heavier but a proportionably ſmall degree of velocity.

It is a famous remark, that the leg of a fly, in its alighting on the ſurface of the earth, moves the whole globe; although the prodigious diſproportion, between the momentum of the body in motion and the weight of that at reſt, renders the velocity of ſuch motion proportionably little; and tho' nothing be more certain than that, if the earth were a perfect ſolid body, the fly would in that caſe give all its motion to the earth, as the fly remains relatively at reſt after the percuſſion.

In the mere *communication* of motion, however, the momentum, or quantity, of it being definite and determined, the velocity of the moving bodies, both before and after percuſſion, will be the ſame; and muſt be definite and determinate alſo.

In the *generation* of motion by draught, the caſe is otherwiſe: for, though the velocity with which motion is generated in a body at reſt, will be proportional to the difference between its own vis inertiæ or weight and that of the body generating the motion, yet, however ſlowly this motion be generated, its velocity will conſtantly increaſe by acceleration, ſo long as the body moved continues to be acted on by the generating power.

A and B, (Figure 1, Plate 1.) are two balls of equal weight. A, lying at reſt, is ſtruck upon by B, in the direction B, C;—after the percuſſion, if the bodies be elaſtic, B will remain at reſt, and A will proceed with the former velocity of B, and in the ſame direction; B having communicated its whole quantity of motion to A. On the other hand, if they are non-elaſtic, A and B will, after percuſſion, both proceed together with *half* that velocity as in Fig. 2; B having communicated to A but *half* its motion; the momentum of which is divided between them. With this velocity, ſhould they meet with no reſiſtance, would they both proceed in the ſame direction ad infinitum. Such is the caſe in the *communication* of motion between a moving body and a body at reſt. In its *generation* between two bodies, both of which are at reſt, it is different. There are but two powers in nature, by means of which bodies at reſt are put in motion. Theſe are elaſticity and gravity. A bent ſpring, or incumbent weight, though both at reſt, while reſtrained or ſupported, will not only begin to move, by unbending or deſcending, when their reſtraint or ſupport is taken away; but, in proportion to their elaſtic force or gravitating power, will give motion alſo to any other moveable bodies, partially impeding that motion in the direction of their compreſſion or gravity; the motion, generated by the dilatation of the ſpring, or the deſcent of the weight, being an accelerated motion, whoſe velocity will be increaſed in proportion to the degree of ſuch dilatation or the time of ſuch deſcent: and theſe will always be proportional to the difference between the moving force and the momentum of the body moved. This is not eaſily experimented in the dilatation of ſprings, becauſe their dilatation is generally too limited and confined both as to ſpace and time: but in the deſcent of weights it is moſt palpably evident.

A (Fig. 3.) is a weight ſuſpended by the running line i, i, over the pully P, and attached by the ſame line to another weight or heavy Body B, reſting on an horizontal plane C, D. While A is ſupported, or B is forceably prevented from ſliding or rolling along the plane C, D; both A and B remain at reſt: but the ſupport of A being taken away, and B left at liberty to move, the force of gravity generates motion in A, and of neceſſity in B; to which A is inſeparably attached by the running line. Now it is well known that the motion of bodies deſcending by their own weight is conſtantly accelerated: and, though it be true that in this caſe the velocity with which the motion is generated in A is leſs than it would have been, if A were not attached to B [*], yet it will continue to increaſe in velocity as it deſcends : ſo that, though A will not in the *ſame* time acquire the ſame velocity as if, being detached from B, it had begun to deſcend faſter, it will in time arrive at any degree of velocity, how great ſoever, provided it meets with no reſiſtance, and A continues to deſcend. Hence it is plain that the ſmalleſt weight whatever, ſuſpended at A, might in time generate a motion of prodigious velocity in B ; even though B were prodigiouſly heavy, and A extremely light. And hence alſo it is plain that the velocity, given to B by the deſcent of A, will always be in proportion to the length or time of that deſcent.

It is by this method of ſuſpending a weight perpendicularly over a pully, that the force required to draw carriages along horizontal and inclined planes, is generally eſtimated. And indeed it is a very good one ; ſince the animal powers, by which their draught is uſually effected, may well be compared to a weight and pully, moved forward in the ſame direction, and with the ſame velocity, as the carriage itſelf ; by which means the ſuſpended weight keeps conſtantly acting on the carriage with the whole force of its gravity, though it never actually deſcends. The truth is, this is not ſtrictly the fact; becauſe in the animal the powers of elaſticity and gravity are united; as will be more particularly ſhewn hereafter *.

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[*] It is true indeed that the acceleration of falling bodies does not depend on their abſolute gravity ; a light body of the ſame ſpecific gravity deſcending in the ſame time as a heavy one ; but in this caſe A is the only deſcending body, which being attached to B, it cannot begin to move with the velocity it would have if detached from it ; it will yet increaſe in proportion to the time of its deſcent.

It may ſuffice our preſent purpoſe to obſerve, that the exertion of both thoſe powers, being limited by the ſize, weight and ſtructure of the animal, the maximum, or greateſt velocity to which it can bring the motion of the carriage on a horizontal plane, can never be greater than that of its own pace, or conſtant local motion. As this pace is again limited by the ſtructure, weight, and muſcular elaſticity or agility of the animal, the velocity of the carriage will always be determined by the velocity with which the animal is capable of acting conſtantly againſt the obſtacles or impediments to the motion once given the carriage.

It is in firſt producing this motion that the animal's centre of gravity is lifted higheſt, and the greateſt force of its muſcular elaſticity exerted. The mere continuation of this motion requires much leſs exertion of power; as, upon horizontal planes, the moving power is required only to be ſomewhat greater than the reſiſtance which the carriage

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* See Part 2. ſect. 7.

riage meets with from friction and other adventitious obſtacles.

In continuing this motion of the carriage up inclined planes a much greater force is requiſite; as the carriage loſes its ſupport, in proportion to the elevation of the plane; and, of conſequence, the load muſt not only be drawn forward, but lifted by the moving power.

Hence it is to be obſerved, in the caſe of animal draught, that there are two principal objects of conſideration; the firſt is, that of affording the moving power its greateſt advantage, in giving motion to the carriage when at reſt; which is done by placing the animal in a ſituation to effect a momentary exertion of his greateſt muſcular force: the ſecond is the facilitating the continuation of that motion when given, ſo that the conſtant exertion of the muſcular force of the animal ſhall be as little as poſſible.

The firſt object of conſideration has induced many to give the line of traction an obliquity; by which means the animal next the carriage is kept conſtantly in the ſituation of lifting, as well as drawing. Indeed Dr. Wallis and others have obſerved that, in the paſſage of wheel-carriages over rough uneven ſurfaces, the oblique line of traction has conſiderable advantages, eſpecially if the wheels themſelves be ſmall. But it is to be noticed that, though the obliquity of the line of traction enables a horſe to exert a greater muſcular force, this exertion cannot be kept up for any time without a proportional fatigue to the animal; who in this caſe acts to the ſame diſadvantage, as if, with a parallel line of traction, it were drawing the carriage up a hill; whoſe declivity ſhould be equal to the obliquity of ſuch line.

In giving this advantage to the moving power, therefore, by ſuch means, the firſt object of conſideration counteracts the ſecond, which is that of facilitating the motion once given a carriage, and fatiguing the animal as little as poſſible in the continuation of it.

As to the ſecond object, viz. the facilitating of the continuation of the motion once generated in the carriage, the methods purſued by the different machiniſts are not only various, but oppoſite and contradictory; as in the caſe of high and low wheels; both of which have their reſpective advocates, and both with like appearance of reaſon. How far it be really ſo, I ſhall endeavour to explain in the courſe of the preſent treatiſe.

From the foregoing conſiderations, draught may be more particularly defined as *the giving motion to a carriage at reſt, and the preſerving the velocity of that motion.*

SECTION II.

Of the means of giving motion to a carriage at reſt.

BY a carriage I mean the mere implement or machine, made uſe of to ſupport or contain the load or weight to be drawn.

As this carriage is alſo itſelf to be drawn with the load, its weight of courſe is added to that of the load; and therefore the weight of every carriage ſhould be as little as poſſible conſiſtent with its requiſite ſtrength.

THE moſt ſimple of all carriages, and that which requires the greateſt force in the moving power to draw it, is a flat ſledge; which, ſliding along the ſupporting plane, requires (if ſuch plane be ſmooth as the ſurface of planiſhed iron, braſs, or hard wood) a force nearly equal to a third part of its own weight, to give it motion along ſuch plane.

I HAVE already obſerved that the ſmalleſt weight, hanging over a pully, and affixed to a body reſting on a perfectly ſmooth horizontal plane, would generate motion in ſuch body

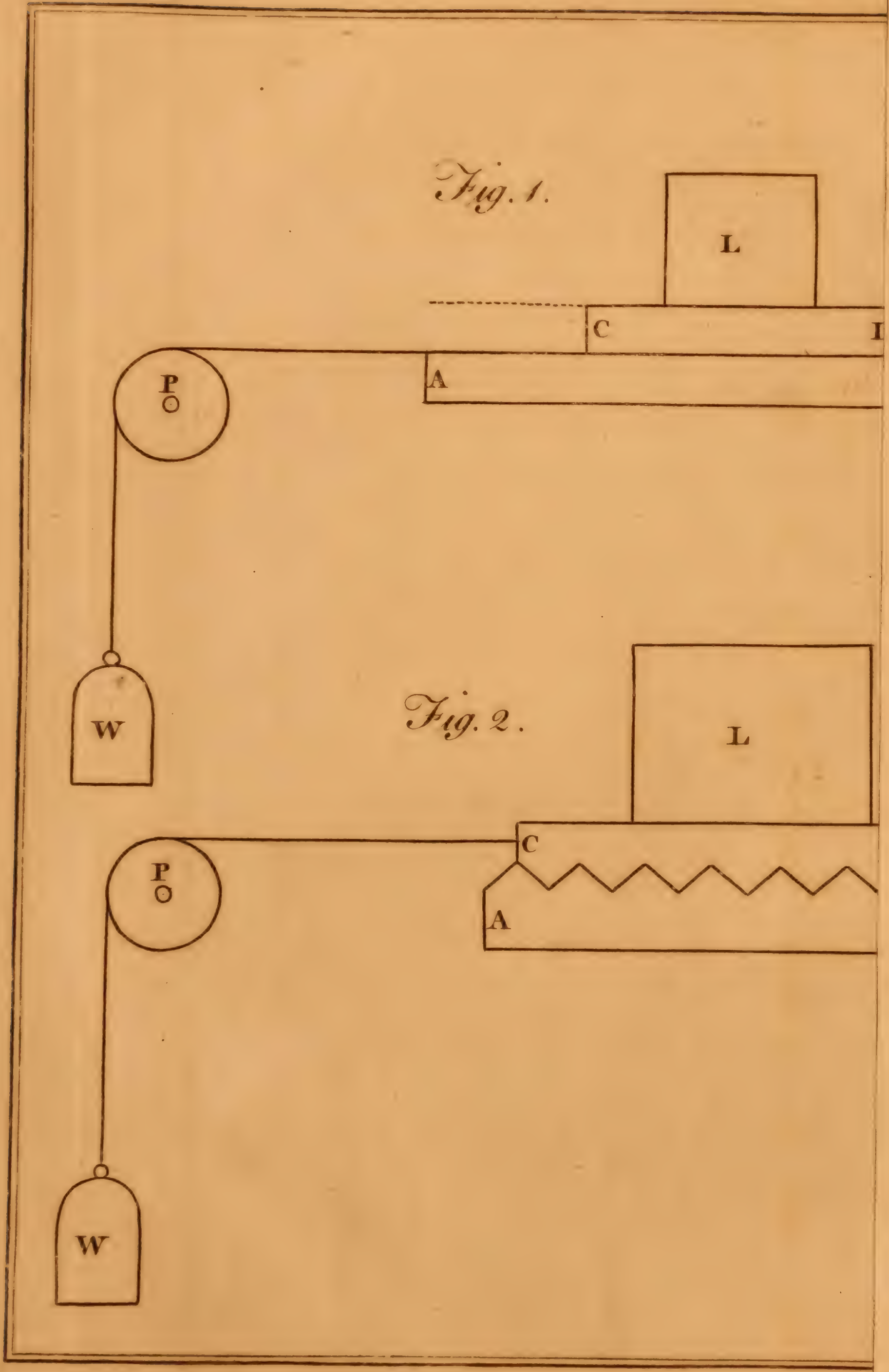


Fig. 1.
L
C
I
P
A
W
Fig. 2.
L
C
P
A
W

body with a velocity proportional to their difference of weight. But if that body be laid on a flat ſledge of braſs, wood or iron, reſting on a ſurface of ſimilar materials, or thoſe of equal aſperity, it will, I ſay, require a force nearly equal to a third of the weight of ſuch body, to generate motion, or to draw the carriage along the plane with any velocity at all.

THIS impediment to the generation of motion in the carriage is called friction, and is uſually accounted for by ſuppoſing that the ſurfaces of no bodies are perfectly ſmooth, however elaborately poliſhed; but that after giving the plane the higheſt poliſh the texture of the body will admit of, there ſtill remain very conſiderable, though impalpable, inequalities on the ſurface: ſo that when two ſuch ſurfaces are in contact, and preſſed together by any force, it requires nearly a third of that force, acting at right angles to the direction of the compreſſure, to make them ſlip or ſlide, one over the other.

NOW, if the planes be placed in an horizontal poſition, the weight of the uppermoſt is this compreſſing force; and, though the ſuppoſed inequalities or roughneſs of the ſurface be impalpable to the naked eye, the ſuppoſition appears nevertheleſs to be well founded; for, were there no ſuch inequalities, there would be no cauſe whatever to prevent the upper plane, ſollicited by any weight hanging over a pully by a running line, from ſliding along or over the ſurface of the under.

To make this apparent to the eye, let A B (plate 2. fig. 1.) repreſent the fixed plane; C D the ſledge, attached by a running line over the pully P to the weight W; and L the load, reſting on the carriage.

Now ſuppoſing the contiguous ſurfaces of A B and C D to be perfectly ſmooth, (as no roughneſs appears) the ſmalleſt weight, as I have obſerved, at W, will put the carriage in motion.

But this is not the real ſtate of the caſe; for we find, by undoubted experiment, that the weight W is required to be a third of the weight of L, to put the carriage in motion.

Instead of repreſenting the ſurfaces of the two planes therefore perfectly ſmooth, let them be repreſented with their ſuppoſed prominencies or inequalities, indented as in fig. 2. plate 2. conformably to the appearance of the ſections of ſuch planes, ſeen through a microſcope.

It is evident to ſight, that the two planes being thus locked, as it were, together, by their mutual indentions, the

Fig. 2.

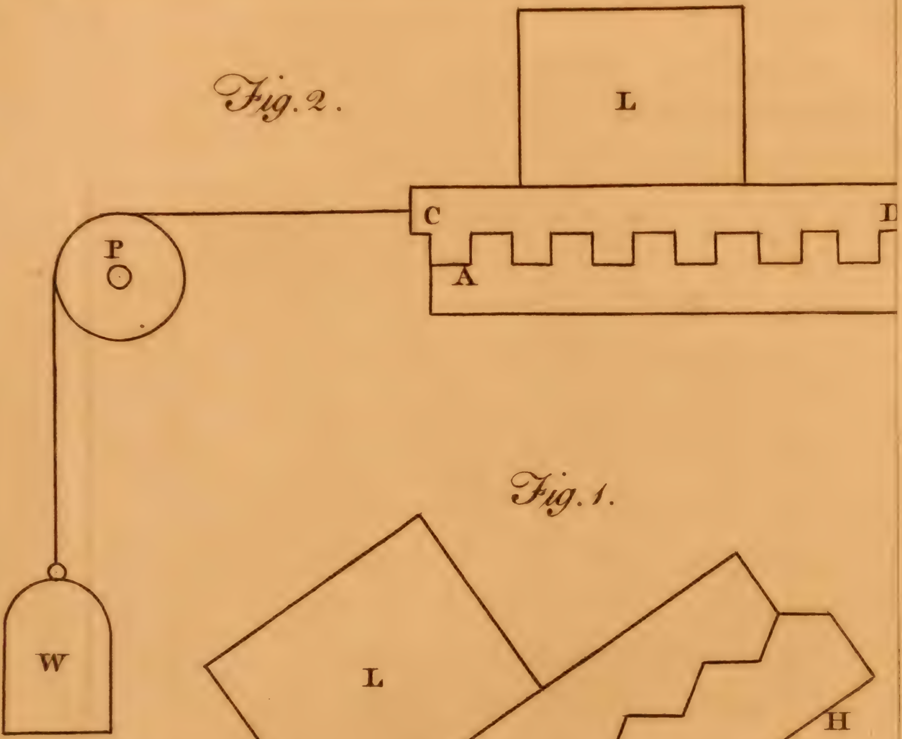
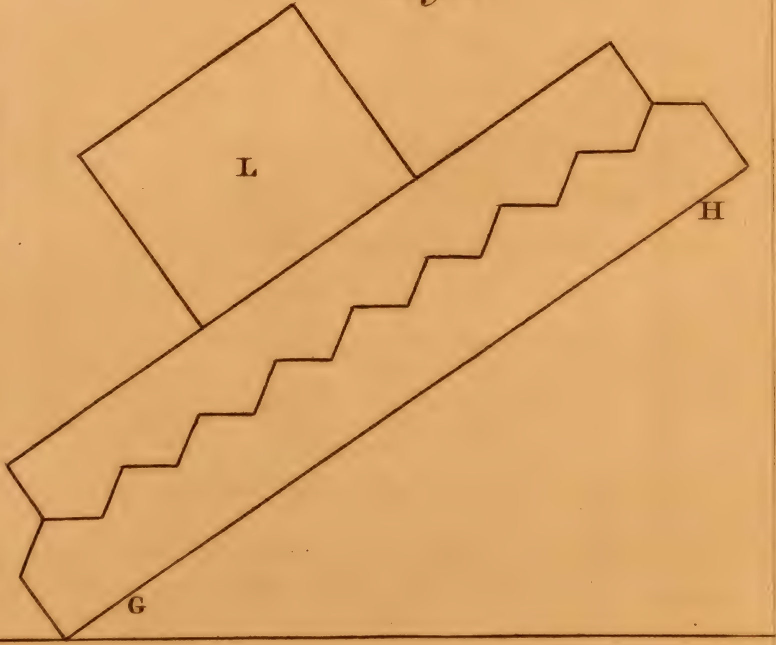


Fig. 1.



the weight at the end of the running line muſt be ſufficient to raiſe the carriage up the inclined planes of ſuch indentions, before it can move. For ſuppoſing, as above obſerved, that the ſurfaces have already taken the higheſt degree of poliſh the texture of their ſubſtance is capable of, it cannot be by reducing the prominences, or rendering the ſurface ſtill more ſmooth, that ſuch motion is effected. The violent friction of highly poliſhed planes forcibly preſſed together, inſtead of increaſing their poliſh, renders them more rough; tearing the bodies themſelves to pieces, or ſetting them on fire. There is required, therefore, a power ſufficient to lift the carriage with its load over the prominences of the ſurface, to give it motion; which power, it is plain, muſt increaſe in proportion to the incumbent weight of the carriage and its load. This will be confirmed by putting the running line and pully out of the queſtion, and giving the planes an obliquity to the horizon, by elevating one end of them till the upper plane of the prominences be parallel to the horizon, as in fig. 1. plate 3; where E F repreſents the horizontal line, and G H the inclination of the planes.

In this caſe the carriage will of itſelf deſcend, or be put in motion downwards with the ſmalleſt force, for want of perpendicular ſupport; its own relative gravity generating motion with a velocity proportional to the obliquity of the inclined plane.

It is apparent from theſe repreſentations, that we are to regard all ſurfaces as raſps, or rather ſingle-cut files, whoſe teeth are lifted over one another, rubbing againſt each other's inclined ſurfaces, as the ſurfaces of the two files appear to ſlide or rub horizontally one againſt the other.

The ratio of the proportion alſo, which in this caſe the weight or moving power appears to bear to the load or weight to be drawn, determines the angle which (in wood, braſs, iron, and the materials generally uſed in carriages) the elevation of the teeth deſcribes with the general plane of the ſurface. For it is clear that if, inſtead of forming triangles, as in the above-mentioned diagrams, the ſections of the teeth were parallelograms, ſtanding perpendicular to ſuch plane, as in fig. 2. plate 3. no weight whatever, hung over the pully and drawing at right angles to the elevation of the teeth, could draw the carriage and load along, or make the plane C D ſlide over that of A B, without breaking the teeth of one or other: and this, by admiſſion, is not to be farther done. Now we find by experiment that about a third of the weight of L, placed at W, is ſufficient ſo to draw it along. We find

Fig. 1.

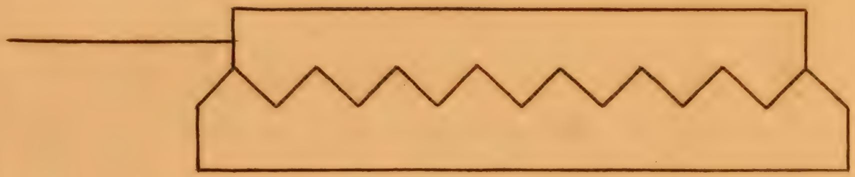
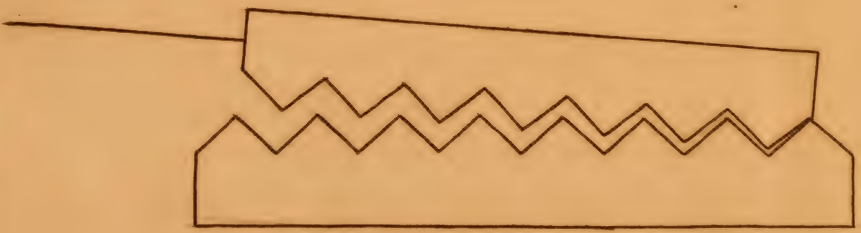


Fig. 2.



alſo by experiment, that, if we give the planes an obliquity of about 20 degrees to the horizon, the carriage and load will be put in motion downwards, by their own gravity. Hence it is plain, that the elevation of ſuch teeth, or the inclination of their ſides to the general ſurface of the plane, cannot be greater than to form the angle juſt mentioned.

This being the caſe, we have here a kind of ocular confirmation of the truth of the experiment reſpecting the reſiſtance occaſioned by friction, as well as a clear information of the reaſon why that reſiſtance increaſes in a direct proportion to the weight. We are led hence alſo to the reaſon why an obliquity in the line of traction is of advantage in draught; as by lifting the teeth of the carriage out of thoſe of the plane upon which it moves, the inclined planes of ſuch teeth are leſs preſſed together in raſion or ſliding over each other. For their parallelism being diſturbed by ſuch obliquity in the line of traction, the upper ones do not touch the under with their whole ſurfaces, as they do when the planes are parallel; but by one's being lifted up at one end, its teeth will paſs more eaſily over thoſe of the under, as is evident by comparing fig. 1. plate 4. repreſenting the teeth, when both the planes are in a horizontal poſition, with fig. 2. on the ſame plane, when the upper is an oblique one.

ADD to this, that a conſiderable part of the weight of the load is thus taken off the plane along which it is drawn, and transferred, in the caſe of the weight and pully, to the pinion ſupporting the pully; and in animal draught, to the back of the animal; ſo that the friction between the two planes is of courſe diminiſhed, with the preſſure of the incumbent weight of the upper one.

SECTION III.

Of the continuation of the motion once given to carriages.

WITH regard to the preſervation of the motion once given a carriage, uſually effected by animal draught, it is to be remarked, as before obſerved, that the animal ſupplies the place both of the weight and pully; drawing the carriage along, partly by means of the weight of its body, and partly by the elaſtic force of its muſcles; its centre of gravity riſing and falling alternately, as it proceeds in the rectilinear direction of the motion of the carriage; ſuch centre being reiterately raiſed up, and at the ſame time puſhed forward, by the dilatation of its muſcles, acting againſt the ground in one direction, and againſt ſuch centre of gravity in an oppoſite direction. For the animal always acts obliquely againſt the ground, in whatever direction be the line of traction in which it draws the carriage.

As the natural compreſſion of its muſcles, however, when it ſtands ſtill and the line of traction is parallel to the plane on which it moves, is proportional only to the incumbent weight of its limbs, its power of draught may be increaſed by artificially increaſing the compreſſion, and conſequently the elaſtic force, of its muſcles; which may be done either by laying a weight on its back, or giving the line of traction an obliquity to the horizon.

To do the former, unleſs with a view to an extraordinary and momentary exertion of power, would be to fatigue the animal to no purpoſe, by making it conſtantly carry what it could more eaſily draw.

In the latter caſe alſo, as the perpendicular preſſure, taken off the plane by the line of traction, is transferred to the animal, it is of courſe the more fatigued by ſuch line of draught; notwithſtanding it is thence enabled to exert itſelf the more forcibly. It is indeed for this very reaſon that it is by ſo much the more fatigued, as, being conſtantly obliged to ſupport part of the weight of the carriage, or, which is the ſame thing, to contract its muſcles with a deſign to lift it, its muſcles are thence the more compreſſed, and though they therefore act with greater elaſtic force, the animal is always fatigued in proportion as its muſcles act under ſuch compreſſion. If this be doubted, let a man keep conſtantly puſhing againſt an immoveable obſtacle, while another makes repeated puſhes againſt a moveable one, rolling or ſliding before him; the former will be equally fatigued, if he puſh with the ſame force, though he ſtand ſtill, as the other who follows the obſtacle as he puſhes it before him.—It is a common experiment for a man to hold his arm extended in an horizontal poſition, to try how long he can ſupport the contraction and play of the muſcles neceſſary to continue that poſture; and the exertion of force, with the fatigue attending it, is very perceptible. But if he ſtoop down, and thence contract the ſeveral muſcles of his body as much as is neceſſary to enable him to lift two weights, one in each hand, perpendicularly from the ground; if thoſe weights be any thing conſiderable, he muſt ſtoop ſo low, and contract his muſcles ſo much, that he cannot continue in that poſture any length of time, without being tortured by the fatigue. Hence the oblique line of traction, though of uſe to put carriages at reſt into motion, is, as before obſerved, very improper for the mere continuation of that motion, when its velocity is once arrived at its required maximum; in which caſe the animal ſhould continue to move with the leaſt poſſible contraction or compreſſion of its muſcles.

PART SECOND.

OF THE STRUCTURE AND DRAUGHT OF WHEEL-CARRIAGES IN PARTICULAR.

THE uſe of wheels, in the draught of carriages, is twofold; firſt, that of diminiſhing (as it is popularly and improperly called, but, properly ſpeaking, the more eaſily overcoming) the reſiſtance, ariſing from the friction of the carriage; and ſecondly the more readily ſurmounting ſuch adventitious obſtacles as, being attached to or preſſed againſt the plane over which it is drawn, form very angular prominences; which muſt be either depreſſed by the weight of the carriage, or require that the carriage, with its load, be lifted over them.

IT is for want of properly diſcriminating between theſe two purpoſes, to be anſwered by the uſe of wheels, that the contending advocates for high and low-wheeled carriages appear both to have reaſon on their ſide. For, though it be certain that high wheels have greatly the advantage of low ones, in overcoming friction; they have not ſuch great advantage as they are ſuppoſed to have, particularly on inclined planes, and in ſurmounting prominent obſtacles; when thoſe obſtacles are indepreſſible and the carriage is to be lifted over them.——But of this more particularly hereafter.

SECTION I.

Of the uſe of wheels in obviating the friction of carriages.

THE firſt and moſt obvious uſe of wheels is to overcome friction, by transferring the raſion, or rubbing, from the under ſurface of the carriage and the plane ſupporting it, to the ſurfaces of the axle and the nave of the wheel; the nave rolling under the axle ſomewhat in the ſame manner as the wheel rolls over the ſupporting plane.

BUT, though a rolling body may be much more eaſily drawn over the ſame ſurface than a ſliding one, its friction is not annihilated or diminiſhed, but its effects only, or the reſiſtance it makes to draught, more eaſily overcome; for the friction itſelf, being proportional to the weight or preſſure of the incumbent body, it will remain exactly the ſame in all caſes. So that, as to the friction of a loaded carriage, it will be likewiſe proportional to its weight, whether it preſs immediately on the plane ſupporting it, or by the intervention of the ſpokes or radii of a wheel; provided the axle or nave be of the ſame materials as the wheel and its ſupporting plane; that is, if the aſperity of their ſurfaces be equal.

The common method of accounting for this advantage, in ſurmounting friction obtained by wheels, is by ſaying that the reſiſtance ariſing from friction in planes of equal aſperity, or equally rough, is that ſuch reſiſtance increaſes with the velocity of the motion; in other words, that the friction is the greater and more difficult to ſurmount, as the parts are rubbed together with the greater ſwiftneſs; ſo that this velocity muſt be compared with that of the power neceſſary to move the machine and overcome the friction. At the ſame time it is obvious, that the velocity of a circular motion diminiſhes gradually from the circumference to the centre. *

But to this it may be objected, that the illuſtration is by no means applicable to the caſe: for, granting that, in the friction of ſledges or flat ſurfaces, ſliding over or rubbing againſt each other, the reſiſtance increaſes in proportion to the velocity of their motion, this is not a parallel caſe with that of a circular ſurface or edge rolling over a flat plane. On the contrary, the velocity of motion in the outer ſurface of a wheel is greater than that of its nave, moving under the axle; while at ſuch outer ſurface there is

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* See Chambers's Cyclopedia. Art. Friction.

is little or no friction at all; whereas at the nave, moving much ſlower, there is much more. Indeed the friction, which the wheel would have againſt its ſupporting plane, did it not turn round its axis, is by its turning round tranſferred almoſt wholly to the axis and nave; whoſe circular motion is notwithſtanding ſo much ſlower. It is indeed notorious that the great friction of the wheels of carriages lies between the axle and nave: how then can it be properly aſſerted that ſuch friction is diminiſhed at the axle, as the velocity of the circular motion is there diminiſhed?

WERE the wheel indeed laid down upon its ſide, the nave and fellows being ſupported by a flat plane, and in that ſituation the wheel turned round its axis, it is certain that the lateral ſurface of the nave would rub leſs againſt ſuch plane than the lateral ſurface of the fellows; and that in proportion to the velocity of their circular motion; which would gradually decreaſe from the periphery to the centre. But, ſet the wheel up on its edge, and let it turn on its axis, in rolling along ſuch flat plane, and the friction, ſo far from being greateſt at the edge of the wheel, where its circular motion is ſwifteſt, will, as I before ſaid, be little or none at all on that edge; but the whole friction will be transferred to the axis and the nave; whoſe circular motion is yet ſo much ſlower.

For it is to be obſerved, that the internal ſurface of the nave does not roll under the ſurface of the axle, exactly in the ſame manner as doth the external ſurface of the wheel over the plane ſupporting it; the motion of the inner periphery of the nave not being equally circular with that of the wheel, nor of leſs velocity in proportion to the difference of ſuch peripheries. If indeed the axis of the wheel were fixed, as above hinted, and the wheel only turned round it, the reſpective velocities of the inner ſurface of the nave and the outer edge of the wheel would bear that proportion *; but, as the axis is carried along progreſſively in a right line while the wheel revolves round it, the motion of every point in the outer ſurface or edge of the wheel deſcribes a cycloid, and that of every point in the inner ſurface of the nave an arch more or leſs cycloidical as it is diſtant from the periphery of the wheel. At the ſame time, the line, deſcribed on the ſupporting plane by the whole periphery, is exactly equal to that periphery and to the right line deſcribed by the centre of the axis, in the rectilinear direction of the draught; ſo that it is plain the local motion or direct progreſſion of the nave is equal to that of the fellows of the wheel. How then is the reſiſtance of friction diminiſhed from the want of velocity in the motion

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* Thus the lateral friction of the wheel, if rubbing againſt a vertical plane, would follow the proportion of the circular velocity, as before obſerved.

motion of the inner ſurface of the nave, when it is evident that the inner ſurface of the nave has rubbed againſt the axle, as much as the axle, or bed of the carriage, would have rubbed againſt the ſupporting plane, had the wheel been taken away, or as the bottom of the outer ſurface of the wheel would have done, had not the wheel turned on its axis ?

It may be ſuſpected this is not a true ſtate of the caſe, becauſe the inner periphery of the nave is ſo much ſhorter than the line of progreſſion, or rectilinear motion of the axis ; but it is ſo for this very reaſon : for, if it be conſidered that the nave is under the neceſſity of turning round as much ſlower than the wheel as its circumference is leſs, the weight of the axis muſt preſs proportionably longer, within any determinate ſpace againſt the inner ſurface of the nave, than it does within the ſame ſpace againſt the outer ſurface of the wheel. Hence the weight bearing longer on each point of the inner ſurface of the nave, in proportion as its length is leſs, the raſion againſt the whole is equal to what it would be, if the periphery of the nave were equal to the line of progreſſion or local motion ; that is, ſuppoſing there were no wheel at all.

It is affirmed indeed by ſome writers, and particularly by Chambers in his Cyclopædia, " that the wheels of carriages,

riages, though they appear to have a double motion, the one circular, about their axis, the other rectilinear, by which they advance along the road, yet in effect they have but one; it being impoſſible the ſame thing ſhould move, or be agitated, two different ways at the ſame time." This one motion, it is ſaid, is a ſpiral one, as is eaſily ſeen by fixing a piece of chalk on the face of a wheel, ſo that it may draw a line on a wall, as the wheel moves.—The line, it is ſaid, which it here traces, is a juſt ſpiral, and ſtill the more curve as the chalk is fixed nearer the axis.

By what means this conceit about the ſame thing moving two ways at once, came to find its way into mechanics, I know not; but the fact related is as falſe as the propoſition is equivocal and abſurd. It is not true, or pretended to be ſo, that the ſame thing moves two ways at once in the rectilinear and circular motion of wheels. The local motion, or motion of the *whole wheel*, is rectilinear only; that of the *parts* of the *wheel* circular. Nor can this latter motion with any propriety be called that of the wheel, unleſs the ſame thing could alſo move quick and ſlow at the ſame time, which the different parts of the wheel, in revolving round its axis, evidently do.

It is alſo ſomewhat ſurpriſing that the pretended fact ſhould continue to be inſerted in the repeated editions of that

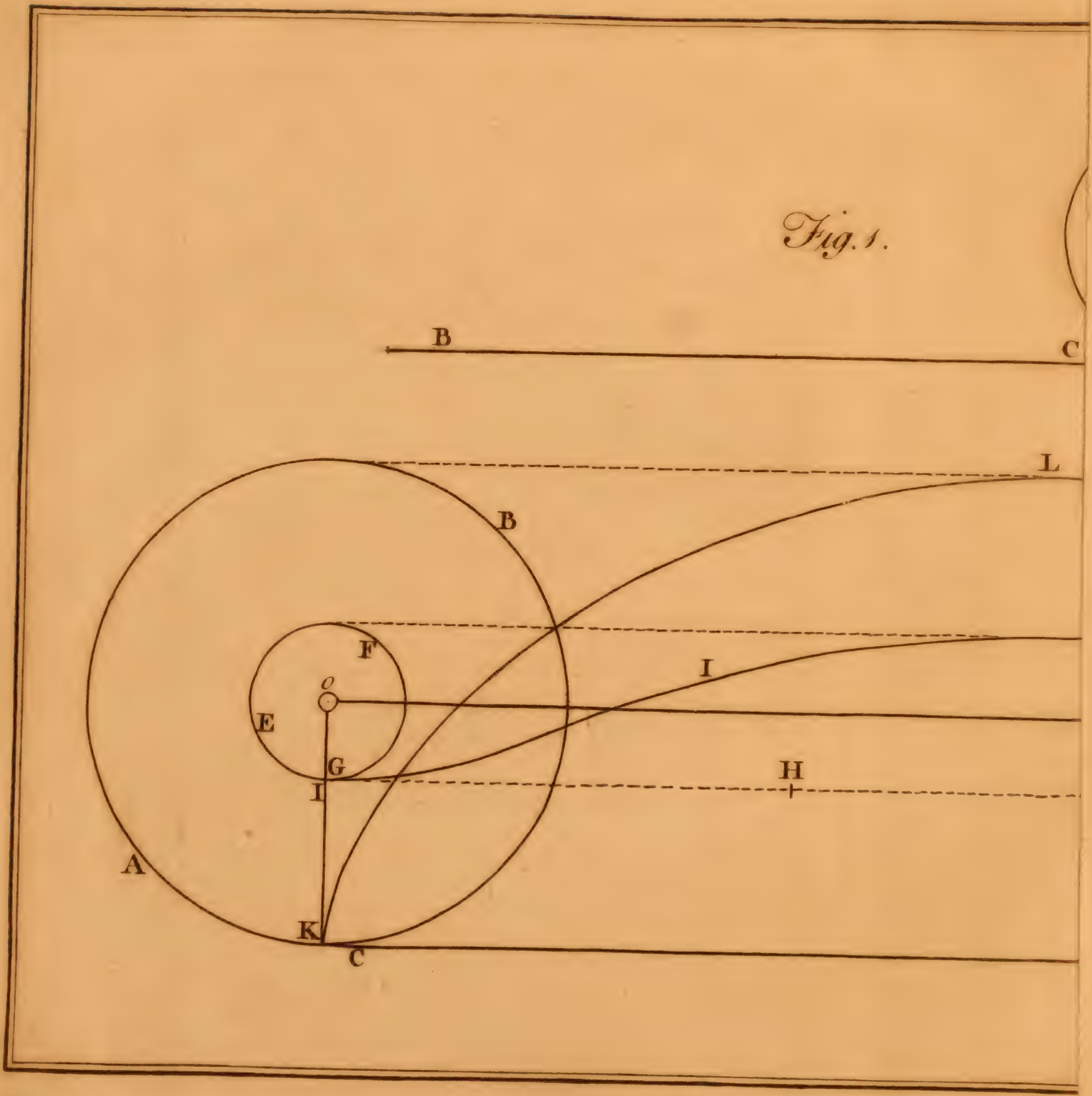


Fig. 1.

popular work; ſince nothing is more eaſy than for any one, who will take the trouble to make the experiment, to prove its falſehood. Place the chalk on the face of the wheel, as directed, and you will find that, ſo far from its deſcribing a juſt ſpiral, and that ſtill the more curve as the chalk is fixed near the axis, the chalk, if placed on the periphery of the wheel, will deſcribe a cycloid, and the nearer it is placed to the axis, the nearer will the line it deſcribes approach to the ſtrait line which is deſcribed by the axis itſelf.

SECTION II.

The friction of carriages not diminiſhed, but only more eaſily overcome, by the uſe of wheels.

TO illuſtrate what has been aſſerted in the foregoing ſection, that friction is not diminiſhed by the uſe of wheels, but transferred only from the outer ſurface of the wheel to its nave and axle, let the circle A (plate 5.) ſtand for the ſection of the axis of the wheel, the line B C for the length of the inner ſurface of the nave, it is plain that, if A roll along B C, the circle being equal to the right line, there will be no raſion or rubbing in the caſe, any more than there is with the external circumference of the wheel and the plane ſupporting it, for that very reaſon, viz. becauſe the line deſcribed between both is of the ſame length.

It is alſo evident that the ſurfaces will rub as little againſt each other, whether the axis A roll over B C, or A remain at reſt, and B C roll round A.

Let us put the caſe then as it really is. A B is the external circumference of the wheel, equal to the right line C D, over which it rolls without ſliding. E F is the inner ſurface of the nave, equal to the right line G H. — I K is the ſpoke, or radius, of the wheel, proportional to whoſe length the velocity of the motion of the ſurface of the nave is ſuppoſed to be diminiſhed; its outer end K being propenſe to move with a velocity much greater than I, as it is farther removed from the centre *o*, the ſection of the axis.

Now the wheel being put in motion, by drawing its axle forward in a line parallel to the plane C D, the outer point of the ſpoke, at K, will deſcribe the cycloid K L C; while the inner end I deſcribes the line I M; when both the one and the other will have moved equally forward the ſpace C D, four times the diameter of the wheel.

It is hence plain, that the velocity of the motion of the inner end of the ſpoke at I is not diminiſhed with reſpect to its outer end K, in proportion to its diſtance from the centre of the wheel, but in proportion only to the difference between the length of the cycloid L K, and that of the cycloidical line I M. At the ſame time it is evident that, if the inner point of the ſurface of the axis, or top of the ſpoke, I, have deſcribed a line ſo much greater than the length of the periphery of the axis, round which it has rolled, it muſt either have rolled ſo many more times round that axle, as G H is leſs than I M, (which from the conſtruction of the wheel is impoſſible) or the inner ſurface of the wheel muſt have ſlid, and conſequently rubbed againſt the ſurface of the axle: becauſe the point of the axle having deſcribed the dotted line H G M, that of G H ſhould have been equal to it, to put it in the ſame circumſtances, as are the outer extremity of the wheel and its ſupporting plane.

This matter might be made ſtill clearer, by ſuppoſing that the wheel were carried along in a right line, without raſion or revolution; and that the axle, in the mean time, were turned round; ſo that its ſurface ſhould move with the velocity which the inner ſurface of the nave would have, ſhould the wheel revolve and the axis be carried forward in a right line. It is plain that, in this caſe, the axis muſt make ſo many revolutions, while the wheel is ſo carried forward in a right line equal to its circumference, as to cauſe any point on the ſurface of ſuch axis to deſcribe a line equal to that which in the other caſe would be deſcribed by any point of the inner ſurface of the nave. This is plain; for it is evidently impoſſible that a ſhort line can be applied to every part of a long one, by merely rolling over it. It muſt neceſſarily ſlide ſo far as the longer exceeds the ſhort. And yet in this caſe the inſide of the nave, which only is actually rubbed, is very little longer than the circumference of the axle: ſo that the long line, to which every part of the ſhort one is ſuppoſed to be applied, is a merely imaginary line and not a rubbing material ſubſtance.

It is to be obſerved, however, that though, the friction of the carriage being in this caſe the ſame, the obſtruction to its progreſſive or rectilinear motion will be equal, ſuch obſtruction does not immediately act againſt the carriage in the direction of its local motion; as is the caſe of friction in the draught of ſledges; but reſiſts that rectilinear motion indirectly or in a different direction; tending only to increaſe the difficulty of the wheel's turning round, and thereby reducing the carriage more to the ſtate and circumſtances of a ſledge: by which means the advantages, to be obtained from the ſpokes or radii of a wheel acting as levers, are prevented.

For it is on the rubbing between the ſupporting plane and the ſurface of that part of the carriage immediately acting on it, that all reſiſtance to draught from friction ultimately depends: for, were theſe planes perfectly ſmooth, no roughneſs on the ſurface of the nave or axis would retard the rectilinear motion of the wheel, tho' it might prevent its revolution on its axis; the wheel in that caſe (that is, the outer planes being perfectly ſmooth) being as eaſily ſlid as rolled over the unreſiſting ſurfaces of ſuch planes.

SECTION III.

The wheel of a carriage not an axis in peritrochio; its ſpokes acting againſt friction merely as ſimple levers.

MISLED for want of duly attending to the foregoing circumſtances, and by the apparent diſproportion there is ſometimes found in the practical effects of high and low wheels, if their ſpokes are conceived to act as levers, many perſons of late have called in queſtion the truth of ſuch conception.

THE radius of a wheel, ſay they, does not act as a lever of any kind in overcoming friction, for it does not reſt on any fulcrum; without which it can be no lever: but in this they are miſtaken; the ſpokes, or radii, of a wheel act as ſingle levers, whoſe fulcra are placed near one end, when the wheel only rolls along the ground, without bearing any incumbent weight, and as double levers, with fulcra placed near both ends, when the wheel turns round an axis, ſupporting a loaded carriage.

Fig. 1.

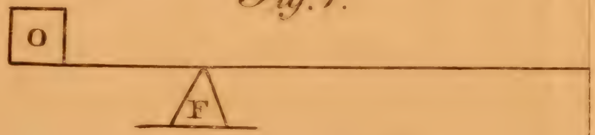


Fig. 2.

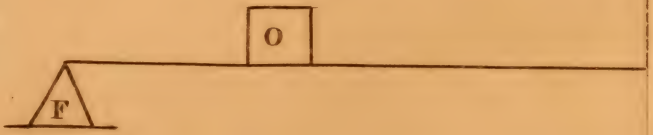
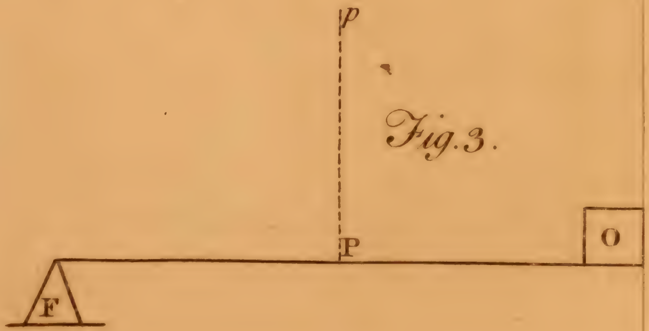


Fig. 3.



It has indeed been inadvertently advanced by thoſe who contend that the radii or ſpokes of wheels act as levers, that the wheel of a carriage acts, in overcoming friction as an axis in peritrochio. The ſpokes, ſay they, are the levers, and the axle, on which the wheel turns, their common fulcrum. But this is by no means the caſe, for then the ſpokes would act as the oppoſite arms of a balance; the power applied to any one, acting againſt a power applied to its oppoſite, and affecting it in proportion to their different lengths from the centre of ſuſpenſion or ſupport. The ſpokes in that caſe would not act as ſimple levers of any kind, tending to overcome the friction of the wheel on its axis, but againſt each other as the oppoſite arms of the ſame balance; whoſe friction on its point of ſupport would be proportional to the weight ſuſtained by both arms, whether thoſe arms were long or ſhort.

To conſtitute the action of a ſimple lever there muſt be three different points of reſiſtance; firſt, that of the weight or obſtacle to be moved; ſecondly, that of the moving power; and thirdly, that of the fulcrum, or point of reſt, on which the lever muſt turn during the operation. To effect this operation, the lever alſo muſt be either that of the firſt kind, in which the fulcrum is placed between the power and the obſtacle; or of the ſecond, in which the weight is placed between the fulcrum and the power; or of the third, in which the power acts between the weight and the fulcrum; as exemplified in plate 6. figures 1. 2. 3. repreſenting the firſt, ſecond, and third kind of levers; O being the obſtacle to be removed, F the fulcrum or prop ſupporting the lever; and P the moving power; which, ſuppoſing the obſtacle a weight to be raiſed, acts in the firſt inſtance downwards, and in the ſecond and third inſtance upwards, in the directions P, p, p.

Now it is very plain, that if we conſider the ſpokes or radii of a wheel as levers, they will always want one of the three neceſſary points of reſiſtance, if their common centre, or inner end of each, be ſuppoſed its fulcrum. In the firſt inſtance, the fulcrum is plainly at ſome diſtance from the common centre of the ſpokes or extreme inner point of each. In the ſecond the obſtacle to be removed is placed between one end and the other; which is not the caſe in the action of the ſpokes of wheels overcoming friction; ſo that the point of reſiſtance of the obſtacle is wanting: and in the third caſe, the obſtacle is at one end, and the ſuppoſed fulcrum at the other; but the moving power muſt act at one of theſe points; and, as I have ſaid, the action of a lever requires three different points of reſiſtance.

The ſpokes or radii of a wheel, therefore, do not act as levers reſting on their common centre as a fulcrum, in overcoming

Fig. 1.

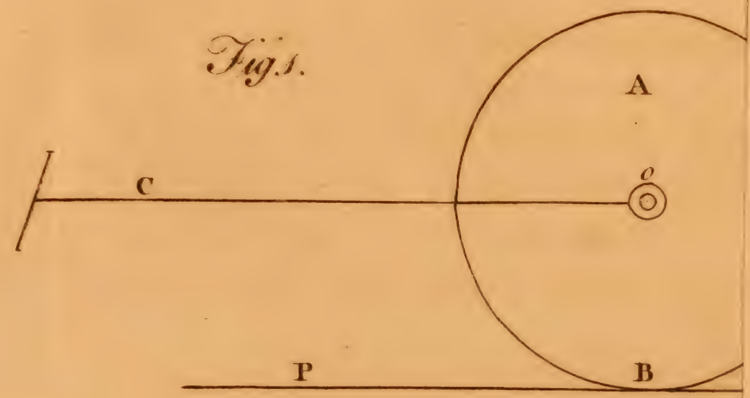
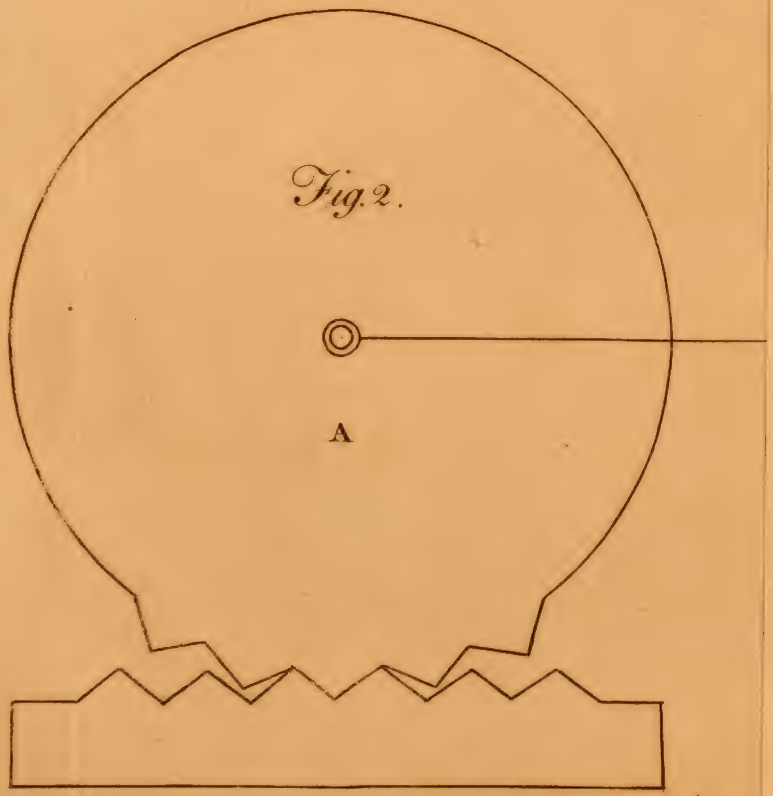


Fig. 2.



coming their own friction either againſt the ſupporting plane, or the friction ariſing from the weight of the carriage reſting upon the nave of the wheel.

But though the common centre of ſuch ſpokes or radii be not their fulcrum, and the wheel does not in this caſe act as an axis in peritrochio, thoſe radii act nevertheleſs as ſimple levers, in overcoming friction, turning upon their reſpective fulcra, viz. the prominences or aſperities conſtituting the roughneſs of the planes; from which ſuch friction ariſes.

SECTION

SECTION IV.

Of the manner in which the ſpokes of wheels act as levers, in overcoming friction.

TO illuſtrate the moſt ſimple operation firſt; that of a wheel rolling along the ground, whoſe ſpokes therefore act only as ſingle levers, to overcome the friction of the periphery againſt the plane of its ſupport; let A B (fig. 1. plate 7.) repreſent a wheel, or the ſection of a garden roller, drawn along by its handle C, reſting looſe on the axis *o*.

SETTING the weight of the handle aſide, the plane P, p, ſupports no other weight than that of the wheel; in proportion to which will be the preſſure on that plane, and of courſe the friction. This, as hath been before obſerved, amounts to about a third of its weight, and if the wheel did not turn round, would require a force equal to a third of ſuch weight in the moving power, to draw it along. But, as the wheel is capable of being turned round, it will be drawn along with a force proportionably leſs, as its centre is diſtant from the plane. This will appear evident, by repreſenting the roughneſs of the planes on a larger ſcale; ſo that their eminences and cavities may be perceptible to the eye, as in a former page, and in fig. 2: in which, to render the matter plainer, the periphery of the wheel is diminiſhed, and the teeth magnified, ſo as to repreſent the weight of the wheel ſupported by a ſingle tooth only; the illuſtration being equally applicable, were it ſupported by ever ſo many.

It is plain that if the roller A had not a circular form, but reſted on the ground with a ſurface equal to its diameter, the preſſure of its weight would be divided between ſeveral of the teeth of the contiguous ſurfaces; but as, from its circular form, it reſts ſolely on one, it muſt preſs with its whole force on that one; ſo that it would require an equal power to raiſe it over that one, as if it preſſed on ever ſo many. The preſſure and friction is therefore evidently not diminiſhed by the circular form of the roller, but only transferred from the inclined ſides of the teeth to the top and bottom of the eminences and cavities conſtituting them.

We now come to the reaſon why a leſs force, in the moving power, will overcome friction in rolling, than it will in ſliding; and this is plainly becauſe that, in the laſt caſe, the centre of gravity of the body reſts conſtantly on one and the ſame ſpoke or radius; which is ever at right angles to the line of traction; ſo that the body cannot move forward without having the eminence, or tooth, on which it reſts, lifted out of the cavity of the ſupporting plane over the next eminence in the rectilinear direction of motion; in which caſe the centre of gravity of the whole is lifted with it: whereas, if the body be free to turn round on its axis, its centre of gravity conſtantly changes its radius or point of ſupport, as it proceeds in the rectilinear line of traction; ſo that the teeth of the upper plane have no occaſion to be lifted immediately over the teeth of the under, as they ſtand in the direction of the wheel's progreſſive motion.

In the meanwhile, it is evident that the reſiſtance ariſing from the preſſure of the eminences of the upper plane into the cavities of the under, is overcome by the radii or ſpokes acting as levers of the firſt kind, and making the tops of ſuch eminences their fulcra; and by that means raiſing the tooth out of its cavity, with a facility equal to the length from the fulcrum to the moving power; the diſtance from ſuch fulcrum to the bottom of the cavity being always the ſame. Even this may be made apparent to the eye, by ſtill magnifying the roughneſs of the planes, and imputing the friction

friction of the top of the eminences againſt the bottom of their cavities to the ſame cauſes, viz. the weight of the incumbent body and the roughneſs of the ſurfaces.

LET S S in plate 8. repreſent a ſegment of the circumference of the wheel or roller above-mentioned.

LET A be the tooth bearing the whole weight of the wheel, whoſe centre of gravity is at B; at which the moving power acts in the direction B P. It is plain that in this caſe the upper point of the eminence C, in the under ſurface U U, will be the fulcrum of the lever B A; and that the moving power will overcome the reſiſtance ariſing from the roughneſs of the bottom of the cavities, expreſſed by the ſmall teeth t t; lifting the point of the great tooth A upwards in the arch e i, whoſe centre is C, with a facility proportional to the length of B b, the longer end of the lever B A. At the ſame time we ſee the reaſon why the centre of gravity of the whole roller is not raiſed by the teeth rolling over one another; becauſe C, being the fulcrum of the lever ſupporting ſuch weight, the radius or ſpoke D, the next in the line of the rectilinear motion of the wheel, muſt deſcend, in proportion as A is lifted up.

NOTHING I think can be hence more evident than that the ſpokes or radii of a wheel act as levers, to overcome

their

their friction on the plane ſupporting them. It will hence alſo follow that a high wheel, of the ſame weight with a low one, will be drawn more eaſily by the ſame power, ſuppoſing it applied to its centre, than the low one; the moving power being alſo in like manner applied to the centre of the low one.

If the weight of the wheel, however, be increaſed, in a certain proportion to its height, no advantage will be gained by that height, and if diſproportionably ſo, it will require a greater force to draw a high wheel than a low one.

The caſe indeed is very different in loaded carriages; eſpecially ſuch whoſe wheels bear but a ſmall proportion, in reſpect of weight, to that of the load they ſuſtain; as will be fully proved, in conſidering how far wheels ſerve to overcome the friction ariſing from the load they are calculated to bear.

SECTION V.

Of the manner in which the ſpokes of wheels act as double levers, in obviating the friction of the wheels in loaded carriages.

IT has been ſhewn, that while a wheel rolls along, without ſupporting any incumbent weight, its ſpokes or radii act as ſingle levers of the firſt kind, ſerving to diſengage the prominences of the contiguous ſurfaces of the wheel and its ſupporting plane, from each other, in the manner deſcribed in the preceding ſection.

BUT when a weight is incumbent on the axle-tree of a carriage, and that axle is ſupported by wheels revolving round it, as ſuch axle is drawn forward in a right line, the radii or ſpokes of ſuch wheels act as double levers, reſting on a fulcrum at each end.

I HAVE already explained the manner in which the radii of a ſimple wheel act againſt the friction ariſing from the preſſure of its weight on the ſupporting plane, by means of the fulcra, conſtituted by the prominences or aſperities of ſuch plane.

It is in a manner nearly ſimilar that the ſpokes act as levers of the ſame kind, to overcome the friction between the inner ſurface of the nave and the under ſurface of the axle. Thus, artificially magnifying the roughneſs of the axle and nave, as we did before that of the wheel and its ſupporting plane, the levers and fulcra will appear as in the following figure; it making no difference with reſpect to the action of the radii as levers, whether the fulcra be urged forward by the rectilinear motion of the axle, or whether the fulcra and axle remain at reſt, and the longer end of the levers be urged the contrary way by the moving power.

Let D (plate 9.) repreſent the axis of the wheel; S S S a ſegment of the inner ſurface of the nave; F G the ſpoke; Q Q a fellow or ſegment of the outer circumference of the wheel, and A B the plane ſupporting it.

It is plain, from the figure, that whether the ſupporting plane A B be drawn backward toward C; while the axis D remains fixed, or that axis be drawn forward toward E; the plane A B remaining fixed, the ſpoke F G will act as a lever a lever againſt the aſperities of the planes at both ends, by means of the fulcra *i*, *k*; the moving power acting at *i*, againſt the aſperities of the ſupporting plane A B, by means of the fulcrum *k*; and at *k* againſt the aſperities of the axle by means of the fulcrum *i*. At the ſame time, the power of the lever will act on both fulcra, in proportion to its whole length.

To illuſtrate this, let us ſuppoſe the ſpoke, or lever, to turn on a centre in the middle at *o*, and the moving power drawing at the axis in the line E D, or rather in the dotted line L, *i*, to be equally divided; one half acting in that line and the other half the contrary way, in the line G, *c*, by the motion of the ſupporting plane A B. It is plain, that the two ends of the ſpoke, being urged equally contrary ways, they will be reciprocally diſengaged with equal facility, by the rolling of the teeth of the contiguous ſurfaces over each other; there being no more raſion at the end F than at the end G.

HENCE it appears, however, that when the whole moving power acts in the Line L, *i*, and the ſupporting plane A B remains at reſt, there will be this difference between the action of the lever at F and its action at G, viz. that, as the circular motion of the nave is ſlower than that of the periphery of the wheel, in proportion to their reſpective diameters, and yet the axis has the ſame rectilinear motion as the periphery, the lever will act longer and preſs harder on the fulcrum *i* than on the fulcrum *k*, and that in proportion as the number of teeth in the inner ſurface of the nave is leſs than the number of thoſe on the outer ſurface of the wheel, notwithſtanding it be ſolicited by the ſame moving power, acting at equal diſtance from each power.

HENCE we ſee the reaſon why the nave and axle rub ſo much more forcibly againſt each other, than the outer ſurface of the wheel does againſt the plane ſupporting it; notwithſtanding the inner ſurface of the nave rolls under the axle nearly in the ſame manner as the outer ſurface of the wheel rolls over ſuch ſupporting plane.

IT is to be remembered that the raſion is here differently effected to what it is in the friction of flat ſurfaces, when the upper ſlides over the under; the teeth of the upper, in that caſe, preſſing with their fore ſurfaces againſt the hind ſurfaces of the teeth of the under; whereas in this caſe the fore ſurfaces of the teeth of the under plane preſs againſt the hind ſurfaces of the teeth of the upper: ſo that did not the friction between the nave and axle tend to increaſe the friction between the outer ſurface of the wheel and that of its ſupporting plane, the preſſure occaſioning it, would rather accelerate than retard the rectilinear motion of the axis.

At the ſame time we have here an irrefragable proof of the fallacy of the notion that friction is in this caſe diminiſhed, merely by the increaſe of velocity in the relative motion of the contiguous ſurfaces ; for it is clear that the inner ſurface of the nave moves much more ſlowly under the axle than the outer ſurface of the wheel over its contiguous plane ; and yet the friction between the ſloweſt moving ſurfaces is here by much the greateſt.

That the diminution of the power neceſſary to overcome friction in this caſe, follows the ratio of the diminution of the velocity of the circular motion, is very certain ; but this is, becauſe the radii of the wheel act as levers in the ſame proportion ; as I preſume hath been fully ſhewn.

To add however a word or two more on the ſubject ; it has been confirmed by innumerable experiments, that the increaſe of friction between ſurfaces equally rough follows the proportion of the incumbent weight on both. I have given a mechanical reaſon why it neceſſarily muſt be ſo, in the caſe of one plain flat ſurface ſliding over another, viz. becauſe the upper ſurface muſt be lifted and drawn up the inclined plane of the teeth of the under.

Now the ſame reaſon holds good in the caſe of the axle and nave, with the difference only in the mode of operation, as before explained. The circular ſurfaces being leſs, the upper is not lifted ſo often, nor over ſo many teeth, but dwells longer and preſſes harder againſt each. So that ſuppoſing all the friction taken away from between the external circumference of the wheel and the plane ſupporting it, becauſe it rolls along a ſpace equal to that circumference, the whole of ſuch friction will be only transferred from the outer ſurface of the wheel to the inner ſurface of the nave: where the weight of the carriage muſt be lifted up the inclined planes of the teeth of the under ſurface, in the ſame manner as if it had ſlid along the ground; with this difference, I ſay, only, that when the wheel is uſed, the moving power acts by means of the ſpokes as levers, with an advantage proportional to their length, to raiſe their weight; the inclined planes of the under teeth in the meanwhile becoming more oblique, from the neceſſity of the wheels conſtantly changing its radius of ſupport, and the nave rolling under the axle.

By the uſe of wheels, the friction, or rubbing, of the outer circumference againſt the ſupporting plane, is, as hath been before obſerved, only transferred from the under to the upper, or rather divided between thoſe ſurfaces and the ſurfaces of the axle and nave. Were the nave nearly as big as the outer ſurface of the wheel, the axis would ſlide nearly all the way; as, the wheel being but little bigger than the axis, and its radii or ſpokes of ſcarcely any length at all, there would in fact be little or no wheel, and conſequently no rolling.

THE caſe therefore appears ſimply to be this, that the motion of the carriage being rectilinear, and parallel to the ſupporting plane, the wheel muſt ſlide nearly the whole length of that plane, and therefore rub all the time either at the axle or at the circumference. The more it rubs at the one, the leſs it will rub at the other; the rubbing at the axle increaſing as its diameter is diminiſhed, and the rubbing at the circumference increaſing as the diameter of the axle is increaſed.

IT will hence follow, that if a method could be diſcovered to make the ſurfaces both of the nave and circumference roll all the way, the friction which attends the rubbing of parallel moving ſurfaces, and increaſes in proportion to the weight of the upper, will be removed, whatever be the proportion which the diameter of the axle may bear to the circumference of the wheel.

Thus if a carriage were drawn over rollers, conſtantly finding a new roller to reſt upon, as it progreſſively paſſed off another, the friction ariſing from the neceſſity of lifting the upper ſurface over the teeth of the under, would certainly be annihilated; and perhaps ſuch a method is practicable. But the caſe is, that if it were practicable, it would be of little uſe; as the diminution of friction beyond a certain degree is of very little conſequence in the draught of wheel-carriages.

SECTION VI.

Of the importance of friction reſpecting the draught of wheel-carriages.

I HAVE been the more prolix and particular in explaining the nature of friction; becauſe it is really an important object to be conſidered in the operation of mechanic engines in general; it is, however, by no means of ſo much importance in preventing the progreſſion of wheel-carriages as hath been generally imagined.

ONE might be led to think, from the experiments uſually made on this occaſion, that friction were almoſt the ſole obſtacle to the draught of carriages; in ſo much that, if ſuch friction were entirely removed or ſurmounted, they would move along horizontal planes of their own accord.

CERTAIN indeed it is, that, were there no friction in the caſe, the ſmalleſt power imaginable might draw the greateſt load along ſuch a horizontal plane: but with what velocity would it draw it? Juſt with as great a velocity as the globe of the earth recedes from the percuſſive weight of a fly. It is ſomewhat ſurprizing that ſo many ingenious experimentaliſts have beſtowed their time and attention on this ſubject, without taking into conſideration the velocity with which the ſeveral carriages were moved by the different powers applied to put them in motion.

THAT the force neceſſary to put a carriage at reſt into motion, is proportional to the friction dependent on its weight and conſtruction, is certain: ſo that of two carriages of the ſame weight, that which is eaſieſt put in motion is comparatively the beſt on this account. But in judging of things comparatively better or worſe, it is neceſſary to take in the different degrees of compariſon, or we do nothing.

THUS, in judging of the comparative excellence of two carriages of different conſtructions, but of equal weight, if we were to conclude that, becauſe the one is put in motion with half the force requiſite to move the other, the one by one horſe, for inſtance, and the other by two; I ſay, if we were to conclude therefore that the carriage which is the eaſieſt moved would be drawn as far in the ſame time by one horſe as the other by two, we ſhould fall into a moſt egregious error.

It were very eaſy to make one carriage of ſuch a weight, that it ſhould be juſt put in motion by two horſes; and another of twice its weight that ſhould be juſt as eaſily put in motion by one; but we muſt not hence infer, that in conſequence of the mere difference in the conſtruction of the carriage, one horſe will be able to draw twice as much weight as two can do, to the ſame diſtance in the ſame time; or that the one carriage is in this caſe comparatively four times better than the other. Yet this ſeems to be the general miſconception of the matter, from the prevailing notion that friction is the principal obſtacle to the progreſs of carriages.

Experience, however, demonſtrates the contrary. It is not many years ago that an ingenious artiſt of Birmingham invented a method, to take off the friction from the axle of carriages; from which he expected prodigious advantages in the draught.

Nay, ſo confident was he of ſucceſs, that he cauſed the words *Friction annihilated* to be inſcribed on the boxes of his wheels. And yet I do not find that his carriage could be drawn faſter, with the ſame number of horſes, than other carriages of the ſame burthen. It has been ſaid, indeed, that the ſmall rollers on which the axle ſhould have turned did not properly do their office; but if they had, it would have ſignified little; the diminution of the friction in theſe caſes to more than an eightieth or at moſt an hundredth part of the whole weight of the load being of no apparent conſequence. The reaſon of ths will more fully appear on recurring to the theory of progreſſive motion.

Before I cloſe this ſection, however, it may not be amiſs to take notice of a late invention, which ſeems to be an improvement of Mr. Wyatt's ſcheme before-mentioned; the ingenious improver having, as I have been informed, obviated the difficulties attending flat rollers, by uſing ſpherical balls, to prevent the rubbing between the nave and the axle.

That a contrivance of this kind, if free from the inconveniencies of lateral ſhocks and compreſſure, would ſave the trouble of greaſing, and in ſome meaſure the wear of the axle and box, is certain. It might alſo tend to facilitate the carriage's being put in motion; but if it be ſuppoſed, as the contriver ſeems to intimate, that becauſe the carriage will be ſo much eaſier put in motion, it will be drawn forward with any certain velocity with a proportionably leſs power, it is a miſtake. Inventions to remove or overcome friction, are of no farther uſe than to obviate the difficulties ariſing from friction. They are calculated merely to hinder the delay occaſioned by the carriage's paſſing over an irregular or rough ſurface; not by any means to urge the carriage along. The power that does this muſt be proportioned to the weight, or rather to the vis inertiæ of the load; in compariſon of which the rubbing between the axle and box in wheel-carriages is a very inconſiderable object.

In reſpect to machines that are not required to move with any great velocity, but will admit of being moved as ſlow as the force made uſe of is ſmall, ſuch contrivances may be extremely uſeful; but where velocity is the principal object, as in the motion of wheel-carriages, the force required to draw them muſt be proportional to the vis inertiæ of the whole load acting in a horizontal direction, and not to the friction ariſing from the perpendicular preſſure of its weight.

SECTION VII.

The theory of draught reconſidered.

IT has been already obſerved, that draught conſiſts, firſt, in the putting a carriage at reſt into motion, and ſecondly in the continuing that motion when arrived at its maximum. With regard to the firſt, it has been alſo obſerved, that it differs, in the mode of operation, from the mere communication of motion from a body already moving to another at reſt. But, though traction differ from percuſſion in mode of action, it makes no difference whatever as to the quantity of the action; the momentum of the motion generated in traction following exactly the ſame ratios of proportion as in that communicated by percuſſion; that is, (conſidering the active body or animal in the caſe of draught, to be the ſame as the moving body in the caſe of percuſſion) the force exerted by the active body will be divided between itſelf and the body to be moved, exactly in the ſame proportions as is the momentum of the motion of the moving body in the caſe of percuſſion.

LET us conceive, then, that the animal or team would be able, by the exertion of its muſcular force to a certain degree, to go forward at any certain rate, without a carriage: let then a carriage of equal weight with the ſaid animal or team be faſtened to it, and it would be able, with the ſame exertion of muſcular force, to draw the carriage forward but half as faſt: that is, ſuppoſing the carriage without friction: if the carriage had friction, its velocity would be ſomewhat leſs.

AGAIN, if the carriage were lighter or heavier than the team, it would be drawn faſter or ſlower in a due proportion; that is, the whole momentum of the team, which is the active power or moving body, muſt be divided between itſelf and the inactive body or the carriage, in the ſame manner as is the momentum of bodies of different weights in the caſe of percuſſion.

So that if carriages of equal weight were to be drawn forward with equal velocity by the different powers, which might be ſufficient nevertheleſs to put them in motion, we ſhould ſee a ſmaller power generate as great a quantity of motion as a larger power; which would be inconſiſtent with all mechanical theory, and incompatible with the laws of nature.

To prove experimentally that carriages will not be drawn forward equally faſt by powers proportional to their difference in point of friction, or to the different powers neceſſary to put them in motion, I took two models of equal weight, but of differently-ſized wheels, and placing them ſide by ſide, cauſed them to be drawn along the floor by means of running lines hung over two different pullies. To the end of the line, faſtened to the higheſt-wheeled one, I hung a pound weight, which juſt put it in motion; to the end of that faſtened to the low-wheeled one I hung four pounds, which had barely the ſame effect.

Now to judge, as ſome have done, from this circumſtance, that the high-wheeled model would be drawn forward with any determinate velocity, by a fourth part of the power that would be neceſſary to draw the low-wheeled one with the ſame velocity, is a groſs miſtake: to prove which, I put two pound to the former, and eight to the latter; when, letting both ſet off along the room at the ſame inſtant, the low-wheeled one, which required four times as great a power to ſet it barely in motion, yet now outrun the other above half-way. I then diminiſhed the weight faſtened to the lower-wheeled carriage from eight pounds to ſix; but it ſtill outrun the high-wheeled one; nor did they keep pace with each other, till I hung the ſame additional weight to the line faſtened to the low-wheeled carriage as to that faſtened to the high one: that is, after the different weights neceſſary to overcome the friction of the two carriages were applied, viz. one pound to one, and four pounds the other, the addition of the ſame weight to each became neceſſary to make them keep pace with each other. I tried this with various weights, and the effect was always the ſame, except that when the additional weights were ſmall, there was ſome little diſcernible difference, on account of the greater obſtruction which the inequalities of the floor made to the little wheels than they did to the high ones. But when I applied a more conſiderable weight, as for inſtance eight or ten pounds, they both kept exactly the ſame pace. Thus, in the laſt caſe, the one was drawn equally faſt by eleven pounds, as the other with fourteen; the comparative excellence of the latter, therefore, could be here only as fourteen to eleven, and not as four to one; which it would be, if we were to judge by the diſproportion between the weights that are barely neceſſary to put them in motion. It is here to be remarked alſo, that the degree of ſuch comparative excellence would diminiſh in proportion as the powers applied were to be increaſed. When the friction of a carriage, therefore, is diminiſhed (as it is called) to about the fiftieth or ſixtieth part of the weight, the momentum of the team, neceſſary to draw it with the cuſtomary velocity, is ſo great, that the farther diminution of ſuch friction, though to ever ſo minute a degree, is an object of very little moment to the progreſſive motion of the carriage. For, how much ſoever we diminiſh or find means to overcome the friction of carriages, there ſtill requires a power or active body of a momentum proportional to their weight, to draw them forward with a certain degree of velocity. And that this velocity is eſſential to the conſideration of the comparative excellence of wheel-carriages, needs hardly be remarked, as expedition ſeems at preſent to be the principal object conſulted in their improvement. But to attain this end, it is not the diminution of friction, ſo much as the diminution of the weight, that is the great object in view. But this in carriages of burthen cannot be diſpenſed with; which, for that reaſon, are under a mechanical neceſſity of being drawn by proportionably ſtrong and heavy teams, and of moving proportionably ſlow; nor will any contrivance to diminiſh friction do more for them than to ſave the wear and tear of the ſeveral parts of the carriage; which however is always the leſs in proportion to the ſlowneſs of its motion.

SECTION VIII.

Of the uſe of wheels in facilitating the draught of carriages.

THE uſe of wheels in overcoming the friction of carriages having been thus ſhewn to be limited, and much more confined than is uſually imagined, with reſpect to facilitating the progreſs of the carriage by means of its ſuppoſed diminution, I proceed to conſider their more immediate utility in this reſpect, viz. the facilitating the progreſs of the carriage.

WERE carriages to move along ſmooth horizontal planes, the uſe of wheels in overcoming friction would be their whole utility; but as they are drawn along roads covered with looſe ſtones and indented with cavities, they are farther uſeful in ſerving to depreſs, or raiſe the carriage over the one, and in raiſing it out of the other.

IT is in this reſpect, as well as in overcoming friction, that high wheels have the advantage over low ones;

though not quite to that degree for which ſome of the advocates for the former ſo warmly contend. Their degree of utility is nevertheleſs very eaſily to be aſcertained in general, both by theory and experiment.

As to the former, it will admit of a geometrical illuſtration.

Let A B (fig. 1. plate 10.) repreſent a wheel of two feet diameter, drawn along the plane C D, by a line parallel to the ſaid plane, and fixed to the centre of the wheel at W. Let O ſtand for the obſtacle over which it is to be drawn, riſing ſix inches from the ſurface of the plane. As it is on this point O, that the oppoſite point in contact of the periphery of the wheel muſt reſt and turn, while the wheel is raiſed over the obſtacle, the lines O, W, and O, B, may be conſidered as the arms of a capſtan; which being of equal length, the power acting at W muſt be equal to the weight preſſing at B: that is, ſuppoſing the power acting at right angles to W, O. In this caſe indeed it muſt be much greater: the dotted line W, P, making a conſiderable angle with the perpendicular expreſſed by the dotted line W, Z. Diſregarding this obliquity, the power in this inſtance muſt be equal to the weight.

LET A B (fig. 2.) repreſent the ſegment of a wheel of eight feet diameter, drawn along the plane C D, by a line alſo parallel to the plane. Let O repreſent a like obſtacle riſing ſix inches above the ſame; on which the oppoſite point in the edge of the wheel turns, while it is raiſed over it. Conſider now the lines O, W, and O, B, to be the arms of a capſtan, as before, and we ſee that the power at W acts at twice the diſtance from the fulcrum or centre of the capſtan that the weight acts at B. Hence it is plain, that a wheel of eight feet diameter has juſt twice the advantage in overcoming obſtacles of a wheel of two feet. It has indeed more, becauſe the line W, Z, in this caſe, makes a leſs angle with the perpendicular line W, P, than in the former caſe.

To prove this by experiment, I took models with wheels of different ſizes, and by applying weights and lines running over pullies, to draw them over various obſtacles, found that the theory, as above illuſtrated, was fully confirmed by practice, viz. that if it requires a certain power to draw a carriage of a certain weight over a certain obſtacle, with wheels of any determinate diameter, it will require wheels of four times that diameter to draw the ſame carriage, over the ſame obſtacle with half that power. As the weight of wheels therefore increaſes, and their ſtrength diminiſhes, in a very great proportion as their diameters, it is in this caſe as in that of friction, the wheels of a carriage may be made ſo large, and conſequently ſo heavy, that it will be leſs eaſily and ſpeedily drawn than if its wheels were ſmaller; notwithſtanding high wheels have in general the advantage, both with reſpect to friction, and alſo with regard to the more readily ſurmounting of obſtacles.

SECTION IX.

On the draught of wheel-carriages on inclined planes.

HAVING ſhewn how far the friction of machines is an impediment to their draught on horizontal planes, and the confined utility of wheels in the removal of that impediment, it will be proper to obſerve how far they are uſeful in the draught of carriages up and down inclined planes. And here it is to be remarked that the reſiſtance ariſing from friction is diminiſhed, as the preſſure of the load againſt the plane is diminiſhed ; which it always is, in proportion to the inclination of the plane : but this diminution is ſo far from being an advantage to draught in going upwards, that the force of gravity counteracts the riſe of the carriage in a much greater proportion than the impediment to its progreſſive motion is leſſened by the means of ſurmounting its friction.

THIS impediment to the draught of carriages up inclined planes, from the counteraction of gravity, is of ſo much the more importance, as the contrivances for overcoming their friction on horizontal planes increaſe the evil, by aggravating ſuch impediment to motion up inclined ones.

In the draught of carriages along horizontal planes, the moving power or team acts almoſt ſolely againſt the *vis inertiæ* of the load; but in the draught of carriages aſcending inclined planes, it acts not only againſt the *vis inertiæ*, which is always equal to the abſolute gravity of the load, but alſo againſt the relative gravity of the load itſelf.

Now this relative gravity regularly increaſing with the inclination of the plane, it were ſuperfluous to make new experiments to prove what has been ſo often demonſtrated, viz. that the reſpective relative gravities of the ſame body on different inclined planes are to each other as the ſine of the angle of the plane's inclination.

This rule holds good in all kind of carriages: but in thoſe raiſed on wheels it is to be obſerved, that the higher the axis is removed from the plane, the farther is the centre of gravity removed out of the perpendicular line of ſupport: ſo that the lower the wheel, the leſs is the relative gravity of the carriage.

Fig. 1.

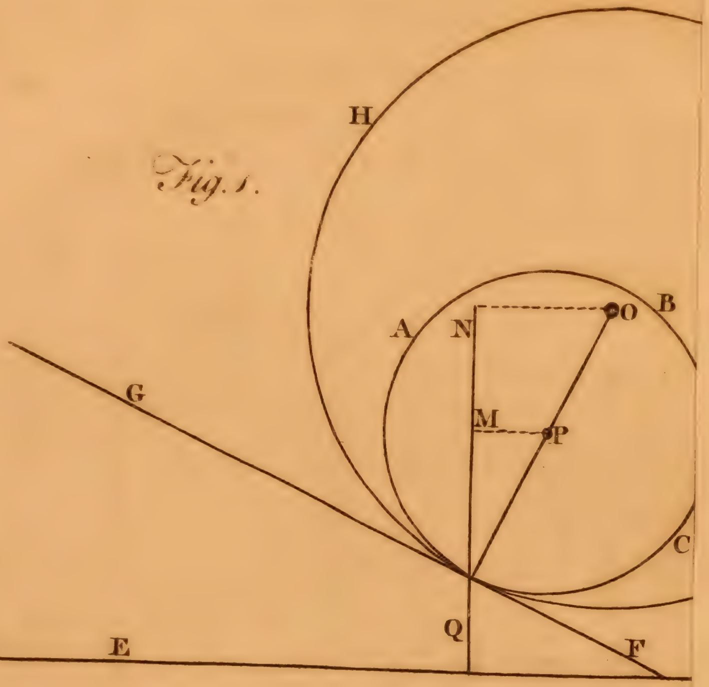
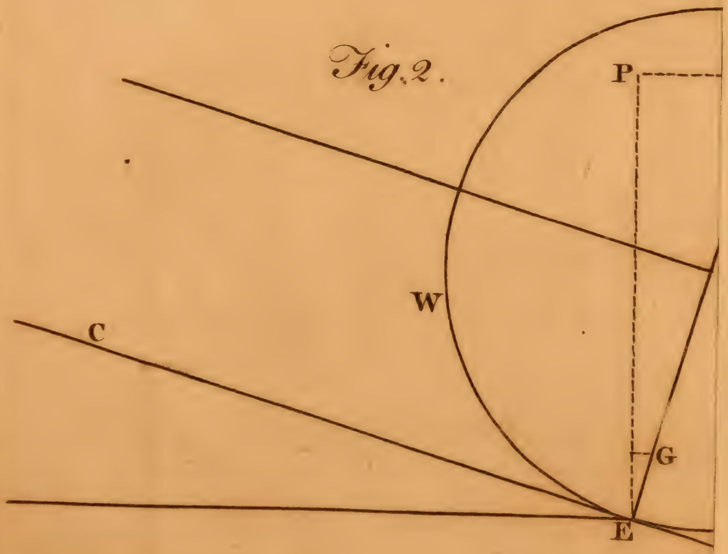


Fig. 2.



Let A B C (in plate 11. fig. 1.) repreſent the periphery of low wheel, whoſe centre is at P, the line E D the parallelism of the horizon, the line G F the inclined plane, up which the wheel is to be drawn, the line N Q a perpendicular to the horizon.—In this caſe it is plain, that the weight of the carriage is no farther removed from the line of ſupport, in which its relative gravity would be nothing, than the diſtance of the line M. P. But let H. I. K. repreſent the periphery of a larger wheel, whoſe centre is at O, and it is equally plain that in this caſe the weight of the carriage would be removed ſo much farther from the line of ſupport, and conſequently its relative gravity increaſed, in proportion as the line N, O, is longer than M, P.

Hence it is evident, that ſuppoſing the friction of two carriages of equal weight, but of different-ſized wheels, to be equal, the low-wheeled one would be drawn up hill, on a ſmooth plane, much more eaſily than the high-wheeled one: notwithſtanding it is certain that on a ſmooth horizontal plane the latter would be drawn more eaſily than the former.

In going down hill, indeed, the high-wheeled carriage will be urged forward, by its relative gravity, more than the low-wheeled one: but this will hardly be accounted advantageous in the former, if we pay due attention to the inconvenience and danger attending the acceleration of carriages down hill.

PART

PART THIRD.

OF THE CONSTRUCTION OF VARIOUS CARRIAGES FOR DIFFERENT PURPOSES.

THERE is nothing more abſurd than the common attachment to cuſtom, in uſing the ſame kind of carriages for very different purpoſes: to each of which ſeverally the conſtruction of the carriage ſhould be reſpectively adapted.

THUS we ſee in London the ſame kind of carts made uſe of to carry coals in ſacks, which are to be ſhifted out and in from a porter's ſhoulders, as for the conveyance of ſugar hogſheads, casks of liquor, &c. which are lifted up and let down again with great difficulty and danger. It were needleſs to multiply inſtances of this kind of miſapplication of the uſe and power of wheel-carriages: the numerous accidents which attend it are known to every body.

SECTION I.

Of carts, and other two-wheeled carriages of burthen.

NEXT to the ſledge, the carriage of the moſt ſimple conſtruction is the cart: the form of which is capable of almoſt infinite variations, to adapt it to the ſeveral different uſes to which it is or might be applied. And yet, except in very few caſes, practitioners appear to have no idea of conſtructing a two-wheeled carriage in ſuch a manner as to receive the load below the axle-tree: a circumſtance which one would imagine the uſe of high wheels would naturally give them occaſion to advert to, and which, in many caſes, would not only be attended with great advantages in loading and unloading, but would ſave the horſes conſiderable labour, eſpecially in the aſcent of inclined planes.

I HAVE already explained from what cauſe high wheels in general are diſadvantageous in drawing up hill: now this cauſe is greatly aggravated in two-wheeled carriages, when the centre of gravity of the load is placed, as it uſually is, conſiderably above the centre of the wheels. For though on plain ground it matters little with reſpect to draught whether that centre of gravity be high or low, yet when it lies much above, and the carriage is aſcending up hill, it will be thrown back, and add to the relative gravity of the carriage much more than it would if the centre of the load lay below the axle.

Let W, W, W, (plate 11. fig. 2.) repreſent the periphery of a cart-wheel, drawn up the inclined plane C, D, it is plain that, if the centre of gravity of the load be placed above the axle at F, it will be farther removed from the perpendicular to the horizon, expreſſed by the line P, E, and conſequently from the point of the wheel's ſupport, than if that centre were placed at G.

In this latter caſe alſo, the weight being placed under the axle, preſſes the ſhafts on the horſe's back, and gives him a greater power of draught, by adding to the firmneſs of his footing; whereas in the other caſe the ſhafts are weighed up, and the horſe lifted off his feet.

The great eaſe with which we ſee ſometimes a ſingle horſe draw heavy water-carts and timber-carriages, whoſe load lies below the axle, is an experimental proof of the utility of placing the load of carts, whenever it can be done, as low as poſſible; ſetting aſide the conſideration of the greater lateral ſhocks and friction which attend high-loaded carriages of all kinds, and the fatal accidents ſo frequent on the practice of ſo loading them.

Another abſurdity, in the uſe of two-wheeled carriages, has of late gained ground in and about London, which is that of increaſing their wheels to an enormous height, and of courſe to an enormous weight; a circumſtance by no means to the advantage of the horſes, when the weight of the wheels bears ſo great a proportion as it uſually does, to the weight of the load. For though ſomewhat be gained in point of friction, and in overcoming obſtacles by the high wheels, this advantage is not equal to what is loſt by the weight or *vis inertiæ* of the wheels; eſpecially if we take into conſideration that the horſes are much leſs relieved by the abſence of the load than in drawing the common cart. So that, granting they drew a full high-wheeled cart ſomething eaſier than a full common one, they draw the empty one with much greater difficulty than they do an empty common one; and this particularly up hill, on account of the greater relative gravity of the carriage.

It is impoſſible to lay down a ſyſtem that ſhall be particular and minute enough to include all poſſible caſes in practice; but it is eaſy, by attending to the outlines of theory, for every artificer to adapt the conſtruction of his carriage to the uſe for which it is intended.

Thus even the rolling carts on low wheels invented by Mr. Daniel Bourne, may in ſome caſes be properly adapted; for inſtance, where the conſolidating a ſoft or looſe road may be the principal object of their uſe. The carriage which might beſt anſwer the ends of the commiſſioners of the turnpikes, is one thing; but that which would beſt ſerve the purpoſes of ſafe and ſpeedy conveyance along the roads, is another. To reconcile theſe different objects of purſuit, is certainly very deſirable; and it may poſſibly in ſome degree be effected; but I am afraid too much is expected from mechanical contrivances: it is in vain to force nature, or to counteract the known and eſtabliſhed laws of mechanics.

SECTION II.

Of Waggons.

WHAT has been ſaid of carts may in ſome meaſure be applied to waggons; with this difference, that having four wheels, they do not reſt on a ſingle axis, as two-wheeled carriages do, but are a kind of ſledge or platform reſting on four points. Their load therefore is not liable to turn round a ſingle centre, and add to their relative gravity, as is the caſe with carts.

NOT but that the height of the load is in waggons of very conſiderable moment in aſcending ſteep hills; particularly if the diſtance between the hind and fore wheels be ſhort, and the greater part of the load is laid on the hinder part of the waggon. This method of loading is nevertheleſs generally adviſed, becauſe the hinder wheels being made higheſt, the load is by this means drawn along the eaſieſt on plain ground. But as relative gravity takes place in aſcending hills, the moſt arduous part of draught, it would perhaps be better, unleſs on very flat roads, to do as Mr. Bourne affirms is done by the common waggoners; who beſt know, ſays he, when their carriage goes moſt eaſy, and therefore very rightly put the greater ſhare of the weight forward.

THE reaſon he gives for it, indeed, is in my opinion a bad one, as he imputes the greater facility of draught in this caſe to the obliquity of an imaginary draught-line between the centre of the fore wheels and the hind ones. But it is paſt a doubt that, on flat ground, the load would be drawn eaſieſt, if the greater ſhare of it were laid on the higheſt wheels, whether they were placed before or behind: ſo that if the common waggoners do place their loading as Mr. Bourne ſays, and find their account in it, with reſpect to facility of draught, it muſt be on the aſcent of inclined planes.

IN waggons, as well as in carts, therefore, the load ſhould ever be placed as low as poſſible, conſiſtent with its ſafety, the nature of the roads, and the convenience of the team and drivers.

AT the ſame time, and for the ſame reaſon, all four-wheeled carriages have an advantage in their length, eſpecially if they are of any conſiderable height.

SECTION III.

Of Coaches, &c.

THE infinite variety, which utility, taſte, and caprice hath introduced into the conſtruction of coaches and other light pleaſure-carriages, hath rendered this ſubject ſo complicated and multiform, that it would be an endleſs taſk to comment on them all, and perhaps it might be thought an invidious one in me to dwell particularly on many: I beg leave therefore to confine myſelf to the ſimple mention of the few improvements which I have myſelf occaſionally attempted, and on which I may with greater propriety addreſs the publick.

PART FOURTH.

OF SOME IMPROVEMENTS THAT ARE OR MIGHT BE MADE IN THE STRUCTURE OF WHEEL-CARRIAGES.

HAVING gone through what I had to offer the public, in reſpect to wheel-carriages, on their preſent conſtruction, in general, I ſhall take the liberty to ſolicit the reader's attention to ſome few attempts which I have occaſionally made, and on ſome others which I conceive might ſtill be ſucceſsfully proſecuted for their improvement.

SECTION I.

Of a new method for the ſhort-turning of wheel-carriages.

IN the turning of carriages of the common conſtruction, the fore-wheels are ſo ſubject to ſtrike againſt the perch, or the ſide of the carriage, that theſe wheels are uſually made ſmaller than the hind ones; and yet carriages are frequently required to turn ſo ſhort, that, even with this diminution, their turning is attended with great inconvenience.

To remedy this, various expedients have been adopted; particularly in coaches, chariots, and other light vehicles, to which the crane-necked perch could be conveniently applied. But as this could not be adapted to the heavier kinds of carriages, and was beſides attended with a conſiderable expence, a thought ſuggeſted itſelf, by which the end might be attained by more ſimple and leſs expenſive means.

Pl. XII.

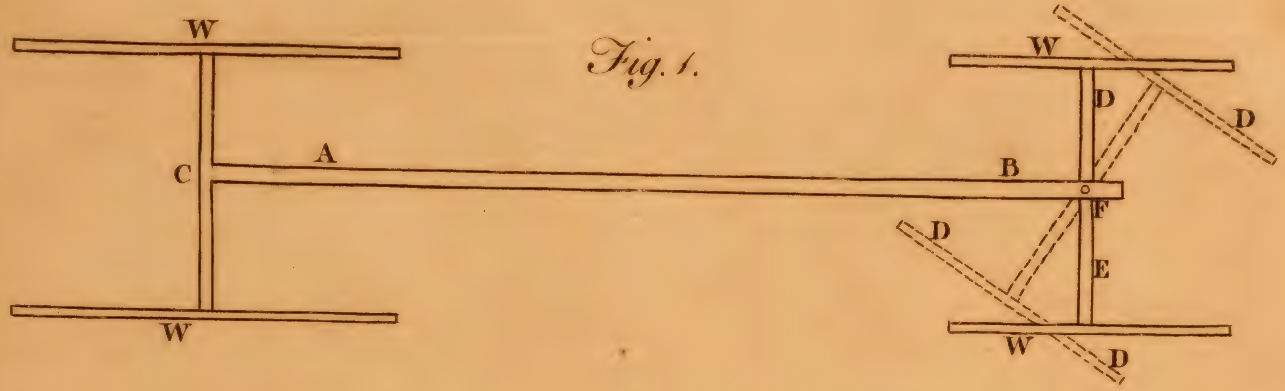


Fig. 1.

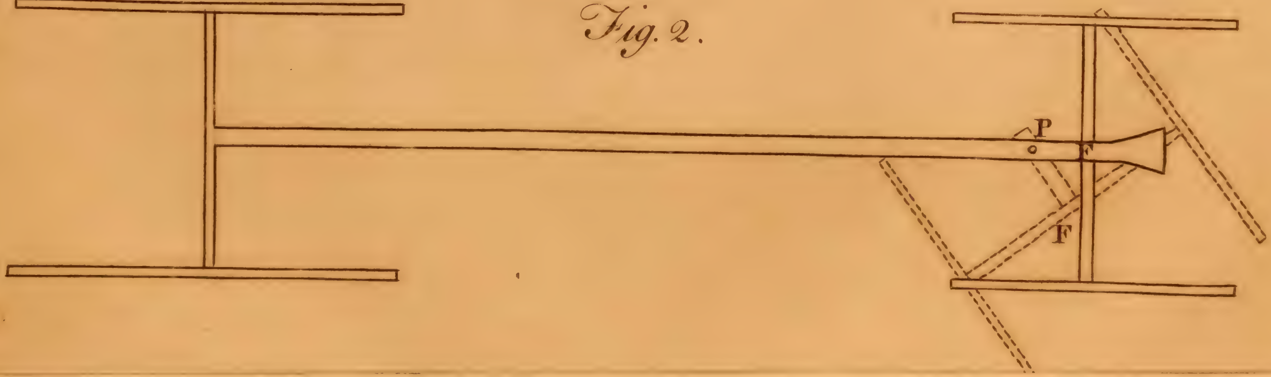


Fig. 2.

According to the common conſtruction the fore end of the perch reſts on the axle of the fore wheels, which turns on the iron pin paſſing through the perch, as deſcribed in plate 12. fig. 1.

A, B, repreſents the perch, paſſing under the body of the coach, and faſtened to the hinder axle at C. D, E, repreſents the fore axle, and W, W, the ſection of the wheels. It is plain, that in turning a carriage ſo conſtructed, the larger the wheel, the ſooner it will ſtrike againſt the perch. In the preſent caſe, the wheel ſtrikes againſt the perch when the axle makes the angle deſcribed by the dotted lines D, D. But if, inſtead of fixing the pin paſſing through the perch at F, in the centre of the axle, we bring a projection backwards from it, as in fig. 2. and let the axle with the wheels turn round the pin paſſing through that projection at P, we ſee the angle, which the wheel makes with the perch, becomes conſiderably leſs, before the wheel ſtrikes againſt it. So that a larger wheel in a carriage thus conſtructed will not touch the perch ſo ſoon as a ſmaller wheel in a carriage of the ordinary conſtruction; and be the wheels of what ſize they may, the carriage will turn ſhorter than if conſtructed according to the former method, with the centre-pin in the centre of the axle.

The reader will readily conceive that this method, being extremely ſimple, is attended with no additional expence, is applicable to all kinds of carriages, and is indeed ſtronger than the uſual mode of conſtruction.

Pl. XIII.

Fig. 2.

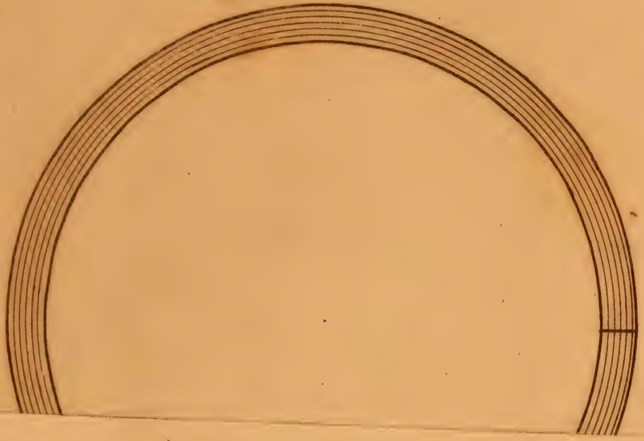
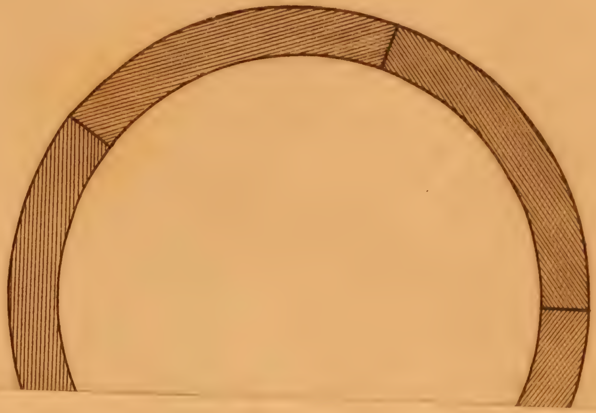


Fig. 1.



SECTION II.

Of the author's new method of conſtructing wheels, with a ſingle rim or two fellows only.

IN the uſual method of conſtructing wheels, their peripheries are compoſed of a number of pieces, or fellows, joined together; which renders them extremely weak, and ſubject to many inconveniencies. In the firſt place, the joints being the weakeſt parts of the wheel, they are moſt liable to yield inward; for which reaſon the wheel-wrights leave them higher than the other parts of the rim; in conſequence of which the wheel is not at firſt exactly round, nor its motion of courſe uniform.

ANOTHER very material objection to this method of conſtructing wheels, is, that the fellows, being ſegments of a circle, ſawed or hewn out of ſtraight wood, they are thence rendered ſo brittle, from the croſs direction of the grain near the joints, that they are with difficulty kept together, even though near twice the quantity of timber be employed as would otherwiſe be neceſſary.

Let A, B, (plate 13. fig. 1.) repreſent the periphery of a wheel, conſtructed after the uſual manner, with five fellows ſawed or hewn out of ſtraight timber; the weakneſs of the rim at each joint, from the croſs direction of the grain of the wood, is palpable. The ſtrength of a wheel ſo conſtructed muſt evidently depend on the thickneſs of the iron teir, or rim, that ſurrounds it: the carriage being thus loaded with a uſeleſs weight both of wood and iron; the latter the more burthenſome and expenſive, as the tire is ſeldom above two thirds worn out before it becomes uſeleſs and incapable of keeping the wheel together.

In the improved mode of conſtruction the caſe is different. By bending the timber perfectly circular, and uſing a ſingle periphery, or two fellows only, the grain of the wood is preſerved in every part of the rim; as we ſee by figure 2. of the ſame plate.

In this mode of conſtruction the periphery of the wheel is equally ſtrong throughout; and though little more than half the uſual quantity of timber is made uſe of, is of itſelf ſtrong enough to ſuſtain the common burthen laid on ſuch wheels, without the aſſiſtance of iron tiers; which are only applied to them as a ſafe-guard, to preſerve the wood from the injuries it would otherwiſe be neceſſarily expoſed to from the roads. Hence a leſs quantity of iron is ſufficient, and even that will be fairly worn out before it becomes uſeleſs.

The durability of wheels of this conſtruction is no doubt a conſiderable object in point of economy to the purchaſers; but their lightneſs in compariſon of others, if attention be paid to what has been before laid down in theſe obſervations, will appear equally an object of importance in the facility and velocity of draught.

If regard alſo be had to the great quantity of timber annually conſumed for this purpoſe, a method of preventing its uſeleſs conſumption may appear likewiſe no inconſiderable object, even as a matter of national concern; eſpecially at a time when it is found neceſſary to import large quantities of ſuch timber from abroad, and there is an univerſal complaint of its ſcarcity at home.

SECTION III.

Of the method of hanging coaches, and other ſlung vehicles.

AMONG many improvements which ſeem requiſite to be made in wheel-carriages, is the removal of that almoſt perpetual agitation or ſwinging which attends on coaches, and ſuch other light vehicles as are ſlung on braces.

A MULTIPLICITY of expedients have been contrived, to prevent the jolting of the carriage being communicated to the body. For this end a variety of ſprings have been invented, and as variouſly applied: but though moſt of them have been in ſome degree uſeful againſt the ſudden and immediate effects of the motion of the wheel-carriage, they have only diverſified or varied the mode of the agitation of the body.

IT is indeed to be doubted whether the motion of bodies ſlung on wheel-carriages be not on the whole as diſagreeable

able and dangerous as that of thoſe which are fixed to the axle; eſpecially in paſſing over even pavements and ſmooth roads. This is particularly experienced on any ſudden ſtoppage of the former, and in their paſſing the ſharp aſcents and deſcents of the pavements and roads.

If the end of riding in a coach were merely to enjoy the exerciſe of being ſwung backwards and forwards, or danced up and down on a ſpring, and to be entertained the mean while with the noiſe inſeparable from the beſt of our preſent contrivances, the uſual methods of connecting the body with the axle-tree would anſwer the end: but as a ſtill and unagitated mode of conveyance ſeems to be the great object at preſent in view, nothing can be more inconſiſtent with that end than the common method of fixing the braces to the bottom of the body.

It is in conſequence of this mode of affixing the body to the carriage, that the centre of gravity of the ſuſpended body is ſo high above the centre of its motion, that it is liable to be continually agitated by the jolting of the carriage, and its danger of overturning increaſed: whereas, if inſtead of practiſing this method, the body were ſuſpended as near as poſſible to its centre of gravity, the agitation of the carriage, as well as its danger of overturning, would be in a great meaſure avoided.

At the ſame time, the various complicated contrivances for counteracting the propenſity of carriages to turn over in oblique lateral ſituations, and in paſſing over prominent obſtacles, would be rendered uſeleſs.

It is hence that ſedan chairs are carried with any kind of ſafety: for, if the poles which ſuſtain the body were fixed to the bottom, the centre of gravity would then lie ſo high above the centre of ſuſpenſion, that the chair would be in continual danger of overturning; and, on the contrary, if the poles were fixed at the top, the centre of gravity would lie ſo low, that it would be impoſſible to overturn it, while the chairmen ſtood upright.

If indeed the poles were thus placed far above the centre of gravity, the chair would be ſubject to ſwing ſideways; but if they were exactly parallel to the line in which the centre of gravity lay, the chair would not be liable to overturn, nor have any other agitation than that ariſing from the elaſticity of the poles.

It is on this principle that I conceive an improvement might be made in the common method of hanging all ſuch vehicles as are now flung in leather braces; eſpecially as our pavements and roads by no means require the body to be hung ſo high as is uſual.

Phaetons and elevated pleaſure-carriages may ſeem indeed to require ſuch a mode of conſtruction; but if it be conſidered that the bodies of theſe are uſually made light, it might even in ſuch caſes be eaſier and ſafer for the rider to have the ſupporters raiſed higher on the carriage, ſo as to ſuſpend the body as near as could be made in anywiſe convenient to the centre of its gravity.

SECTION IV.

Of the breadth of wheels.

THE utility of broad-wheels, in amending and preſerving the roads, has been ſo long and univerſally acknowledged, as to have occaſioned ſeveral acts of the legiſlature to inforce their uſe. At the ſame time, the proprietors and drivers of carriages appear to be convinced by experience, that a narrow-wheeled carriage is more eaſily and ſpeedily drawn by the ſame number of horſes than a broad-wheeled one of the ſame burthen.

It is no wonder therefore that private intereſt, operating againſt public good, ſhould have ſuggeſted expedients to elude the reſtrictions individuals were laid under; or that the letter of the law ſhould be more attended to than the ſpirit of it.

Hence it is that we have lately ſeen the broad wheels of waggons, which, by act of parliament, ſhould preſs a ſurface of nine inches, in reality bear only on one of about three; ſome of them by means of bevelling the edges, and raiſing the middle, of the periphery, and others by bevelling the whole periphery, and having the inner edge conſirably higher than the outer.

THE conſequence of this evaſion of the laws has been that of grinding the materials, made uſe of for mending the roads, into powder, much ſooner and more effectually than when narrow wheels were in uſe, with carriages of leſs burthen. In the meanwhile, the proprietors of waggons do not find the advantages, from theſe modes of conſtructing their wheels, unleſs on clean pavements or very hard roads, which they ſeemed to expect.

INDEED the reaſon of this greater difficulty and delay in the draught of broad-wheeled carriages, does not ſeem to be well underſtood. It is imputed, as uſual in almoſt all caſes of this nature, to an increaſe of friction; but this is in a great meaſure chimerical; if by the quantity of friction we are to underſtand the rubbing occaſioned by the perpendicular preſſure of the weight.

IT may be clearly proved by experiment, and is now univerſally admitted among ſkilful practitioners, that the friction follows the ratio of the weight, and not of the ſurface;

ſo that though a broad wheel bears on more points than a narrow one, the weight on each point is proportionably leſs, and conſequently the quantity of friction the ſame: that is, conceiving the points of ſupport to be immoveable, and to conſtitute the roughneſs or irregularity inſeparable from the plane. In paſſing along the roads abounding in looſe ſtones and other obſtacles, which a narrow wheel may avoid paſſing over, and a broad one muſt ſurmount, the caſe is very different. Here the broad-wheeled carriage will certainly be drawn leſs eaſily, and leſs ſpeedily, than a narrow-wheeled one, though not on account of any additional friction ariſing from the preſſure of the weight on a greater quantity of ſurface.

THE caſe is, there are innumerable ſmall obſtacles, which a broad wheel muſt either ſurmount or depreſs, while a narrow one may evade them by going between and turning them aſide: but as this is the very circumſtance, viz. the prevention of ruts, on which the utility of broad wheels is chiefly founded, the inconveniencies ariſing from this circumſtance muſt in ſome meaſure be put up with.

NOR will this be acceded to with reluctance, if the proprietors of heavy carriages would judge of the difficulty and delay of draught rather by the fatigue of their cattle than the wear of their carriages.

It is true, that the reſiſtance ariſing from lateral friction, owing to any twiſt or partial compreſſure of the axle and the wheels, will ſometimes occaſion an obſtacle to the progreſs of the carriage ; but even this will not laſt long in heavy carriages, be their materials as hard as they may, if ſuch obſtacle bear any conſiderable proportion to the force neceſſary to their draught. In ſuch a caſe the materials will either take fire, tear each other to pieces, or work themſelves together ſo cloſely that the wheels will no longer turn round at all. If the wheels continue to turn, with whatever apparent difficulty, ſo long as the rubbing ſurfaces continue ſmooth and ſeparate, the reſiſtance ariſing from ſuch friction will, I ſay, be inconſiderable, compared to the power neceſſary to the draught.

This will appear plain, on reflecting that the boxes of wheels of any certain diameter will be juſt twice as much worn in going any certain diſtance, as the boxes of wheels of twice that diameter, ſuppoſing the load of both of equal weight. But are we hence to conclude, that the load laid on the wheels of the leſs diameter would require twice the power to draw it the ſame diſtance in the ſame time ? By no means. It is totally contradictory to experience.

It muſt be admitted, that the friction of carriages is greatly diverſified by the inequality of the ſurfaces of the roads ; and this diverſity is greater in broad than in narrow-wheeled carriages ; which occaſions a greater wear and tear of the box and axle in the broad than in the narrow, although both, if conſtantly moving in a vertical poſition, would be exactly the ſame.

By wear and tear I would be here underſtood to mean the deſtruction of the form of the box and axle by a partial and unequal preſſing of the parts originally fitted, or anſwering to each other. In proceſs of time indeed, let the bearing be ever ſo equable, both box and axle will wear out ; but though this may be called the wear, it cannot be called the tear, of the parts. So that what appears to be frequently an increaſe of friction, is nothing but a partiality of bearing in the perpendicular preſſure of the weight : which, inſtead of reſting on the whole ſurface allotted to it, reſts only on a part.

Now there needs little illuſtration to ſhew that the vertical poſition of a narrow wheel is leſs liable to be diſturbed than that of a broad one. Broad-wheeled carriages therefore, conformable to the act, are not only ſubject to more wear and tear than narrow-wheeled ones, on the account of friction, but are drawn more ſlowly and difficultly, on account of the more numerous obſtacles they encounter from their greater breadth of ſurface.

Pl. XIV.

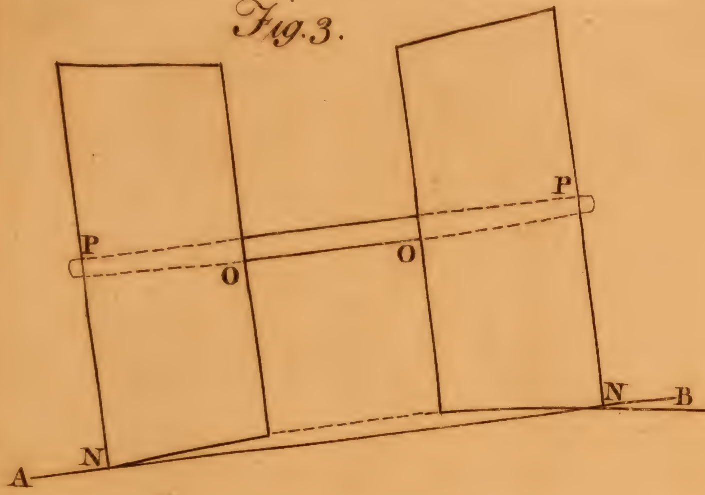


Fig. 3.

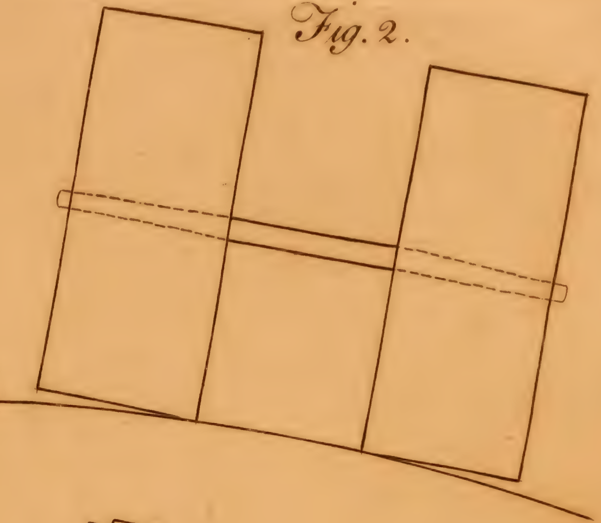


Fig. 2.

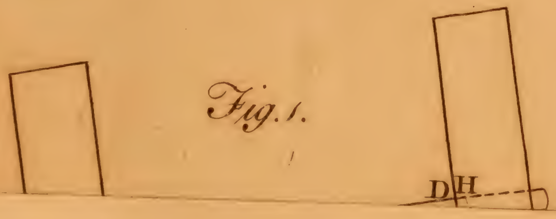


Fig. 1.

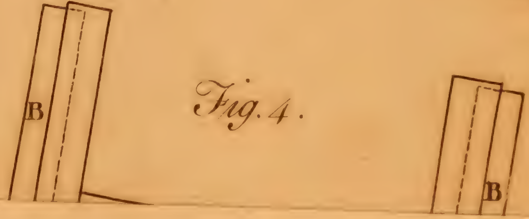


Fig. 4.

To prove that broad wheels are more liable to an inequality of preſſure between the axle and box than narrow ones, let A, B, plate 14. fig. 1. repreſent the ſection of a road, C, D, the axle of a carriage, whoſe wheels are nine inches. Now, ſuppoſing the wheels to ſtand at right angles with the axle, and the ſole or rim of the wheel to be perfectly flat, the weight of the load will reſt on the inner edges only of the wheels, E, F. In conſequence of this, the ends of the axle, inſtead of having an equal bearing through the whole length of the box, will be violently pinched at the bottom G, G, and at the top H, H.

If we ſuppoſe the breadth of the wheel farther increaſed, to two feet for inſtance, as exemplified in fig. 2. this partiality of bearing between the box and the axle will be more conſpicuous.

It may be pretended indeed that the ſole or rim of the wheel may be ſo bevelled, in a due proportion to the diſhing of the wheel, and the convexity of the road, as to give a flat bearing to the whole ſurface of the rim; but as the convexity of different roads is not the ſame, and that of the ſame road in different places very different, the evil is not thus to be removed.

We will, for inſtance, ſuppoſe the ſole of the broad wheels, fig. 2. bevelled to the ſection of the road, as in fig. 3. it is plain, that if they paſs over the flat ſurface denoted by the ſtraight line A, B, (and ſuch flat ſurfaces will frequently happen in the beſt roads) the wheels, inſtead of bearing on their inner edge, as in fig. 2. will reſt on their outer edges, N, N. Hence the friction will in this caſe be as partial between the axle and box as before, though at contrary ends, as at O, O, and P, P. Such is the inconvenience attending broad wheels.

As the preſervation of the roads, however, ſeems to urge the neceſſity of having the wheels of heavy carriages as broad as can poſſibly be made convenient, and the breadth aſſigned them by the law appears, for the reaſons above given, to be too great, it were adviſable perhaps to diminiſh the breadth of the wheels in common ſtage-waggons to ſix inches, and by making the fore and hind axle of different lengths, to cauſe both wheels to roll the full ſurface of nine inches; which they might well do, without admitting of any ridge or vacuity between them; as exemplified in fig. 4. where A, A, denote the ſections of the hind-wheels, and B, B, thoſe of the fore-wheels; which, being of equal breadth, will both together roll a ſurface of nine inches. At the ſame time, the fore-axle being proportionably longer than the hind one, no ridge can be thrown up between the tracks of the wheels; which being only ſix inches broad, will, by leaving a little room in the box, ſtand nearly flat in all ſituations ariſing from the convexity or concavity of the roads.

SECTION V.

Of the diſhing of wheels, and the bending the ends of axle-trees.

BY the diſhing of wheels is meant, the concavity of the outer ſurface: the moſt common and obvious reaſon for which is, that when a carriage leans ſideways, the load lies heavier on the wheel or wheels on one ſide than the other; ſo that, were the ſurface of a wheel perfectly flat, the ſpoke immediately ſuſtaining the weight would in ſuch caſe be out of the perpendicular: whereas by the wheel's being diſhed, it would be nearer a vertical ſituation, and of courſe the better able to ſupport the weight.

THE reaſon is a good one for making the ſurface of wheels ſomewhat concave; but our common wheel-wrights have another practice, which, as they cannot well account for it, I ſuſpect is not quite ſo reaſonable: this is, the bending the arms of the axle-trees downwards, ſo as to make the wheels ſtand conſiderably wider from each other at top than at bottom. The univerſality of this practice would indeed make one apt to ſuſpect that there muſt have been ſome better reaſon for it originally than ſeems at preſent readily to be given by the artificers; who, nevertheleſs, are as tenacious of the practice as if they could aſſign the moſt cogent and mechanical motive for it.

THERE can no doubt be made, however, that this practice occaſions a great deal of partial rubbing, and therefore not only wears the parts in contact, but in ſome degree retards the progreſs of the carriage: and that becauſe, while the axis is carried in a ſtraight line forward, the wheel is propenſe to turn away from the carriage, on account of of the inclination of the ends of the axle downwards.

THE ends of axle-trees are likewiſe ſometimes bent inwards as well as downwards; ſo that the wheels are nearer together at the fore edge next the horſes than behind. Hence from the tendency of the wheels to motion in two different lines of direction, in conſequence of their poſition on the axis, it is evident a very great increaſe of partial rubbing muſt neceſſarily enſue.

THE reaſon for thus turning the ends of the axle-tree inwards I could never learn, except indeed it be that given by ſome of the London wheel-wrights; who tell us it was neceſſary in town-carriages, on account of the deep kennels in the middle of the ſtreets: out of which the horſes could more readily draw the wheels when they ſtood in the poſition above-mentioned. But granting this the true reaſon, the practice ſhould have been confined to town-carriages only, and ſhould be aboliſhed, now our ſtreets are differently paved. When the cauſe ceaſes, the effect ſhould ceaſe of courſe.

Were wheel-carriages to paſs over perfectly flat ſurfaces, there would be no manner of occaſion for their wheels to be diſhed: and if the wheels were not diſhed, the ends of the axles ſhould be perfectly ſtraight, that they might not counteract the rectilinear motion of the carriage; but as they are generally diſh'd, for the reaſons above given, a very ſmall inclination of the axle-tree downwards is neceſſary to give the wheel a free rectilinear motion. This inclination however ſhould be proportional to the concavity of the wheel: the only rule that can be given in this caſe being to balance the wheel vertically as it reſts on the ground; and then to bend the end of the axle-tree downwards, juſt ſo much as is neceſſary to keep the wheel in the line of direction, in which it would ſupport itſelf upright, and move forward in a right line without conſtraint.

But I avoid dwelling on theſe practical minutiæ, as they chiefly ſerve to increaſe the wear and tear of carriages; a circumſtance which, being ſo obvious to ſight, one would imagine might eaſily point out their remedy. Certain it is, they are by no means ſo conſequential as the objects which I have had principally in view in theſe obſervations, and which I have endeavoured to elucidate, I hope, in ſome degree, to the ſatisfaction of my readers.

THE END.

ERRATA.

Page.	Line.				
15	24	*For*	ſame plane	*read*	ſame plate.
30	4	—	Plate 5.	——	fig. 1. plate 3.
31	1	—	A B	——	A. B. fig. 2.
	8	—	velocity much	——	velocity ſo much.
	13	—	K L C	——	K L D.
	16	—	four times	——	about three.
63	13	—	perpendicular	——	horizontal.

Direction for placing the Cuts.

Plate 1.	Oppoſite Page	3.
2.	———	11.
3.	———	13.
4.	———	14.
5.	———	29.
6.	———	35.
7.	———	37.
8.	———	41.
9.	———	43.
10.	———	61.
11.	———	67.
12.	———	79.
13.	———	81.
14.	———	93.